ZENON

ZENON Environmental Inc.

CONTRACT SERIAL NUMBER: OSQ85-00194

MEMBRANE PROCESSING OF OIL FIELD PRODUCED WATER FOR ENHANCED OIL RECOVERY (EOR) STEAM GENERATION

FINAL REPORT

VOLUME I

Report Prepared for

CANMET/ERL Energy Mines & Resources

Prepared by

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MICROMEDIA

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March 31, 1987

Dr. Brian Farnand
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Department of Energy, Mines and Resources
555 Booth Street
Ottawa, Ontario
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Dear Brian:

Re: **Membrane Processing of Oil Field Produced Waters for Enhanced Oil Recovery (EOR) Steam Generation**
DSS File No. 03SQ.23440-5-9111

Enclosed, please find 3 copies of the Final Report for the above named contract. This report is submitted for your approval and will fulfill our committments for work on this contract.

We are very encouraged by results obtained in recent tests which have shown improvements in system performance using a modified membrane composition, increasing the pH of the produced water and operating at temperatures up to 85°C.

We are looking forward to the possibility of operating a test system at an EOR field site to obtain additional information on the practicality of operation using the cross flow ultrafiltration system.

If you have any questions or concerns, please do not hesitate to call.

Yours truly,

Thomas A Krug

Thomas A. Krug, P.Eng.
Project Manager

TAK/mp
Encl.
3074FL

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SUMMARY

Cross flow ultrafiltration systems, which have been successfully applied to the treatment of emulsified oils in many industries, may provide a valuable alternative to conventional treatment of oil field produced water emulsions.

Samples of produced water were obtained from different EOR sites in Western Canada for initial characterization work to determine some of the variability which exists from site to site and from different locations in the treatment process. Tests were then conducted using flat sheet membrane test cells and a sample of wellhead produced water at temperatures of 65°C, 75°C, and 85°C. In these tests, the highest flux obtained was slightly over 1.0 m^3/m^2/day and there was no improvement in membrane performance at elevated temperatures. A similar sample of wellhead produced water containing a high level of oil (1,700 mg/L) was then tested using 1/2 inch tubular membrane modules with much higher levels of turbulence than the flat sheet test cell. Membranes of 6 different chemical formulations were tested. In these tests, stable flux rates of 5.0 m^3/m^2/day were obtained with several of the membranes tested. All membranes rejected virtually all suspended oil and solids and the rejection of dissolved organics varied from membrane to membrane. A CHP thin film composite formulation was selected for further work on the basis of its stable flux and superior rejection characteristics.

A series of thirteen experiments were then conducted using produced water obtained from eight different enhanced oil recovery operations in Western Canada to determine if the high and stable flux rates obtained with produced water from the first site could be

obtained with samples from other sites and different points in the treatment process. The results of these tests demonstrated that the performance of the membrane system is highly site specific and flux rates ranged between 1.0 m^3/m^2/day and over 4.0 m^3/m^2/day with samples from different EOR sites. The performance of the membrane system does not appear related to the level of oil present as much as it is to the stability of the emulsion.

A final set of tests were conducted to optimize a number of factors affecting system performance including the membranes used, the operating strategy used to process the produced water and the chemistry of produced water itself. These tests demonstrated that significant improvements in system performance are possible with samples which previously had poor flux rates, by some simple means, such as optimizing the membrane formulation, increasing the pH of the feed, and increasing the system operating temperature. These tests also suggested that operation with a lower transmembrane pressure may be more suitable for full scale system operation.

An economic assessment demonstrated that the cost of treatment using an UF system, based on the most expensive of the three membrane modules costed, is comparable with conventional treatment at flux rates greater than 3.0 m^3/m^2/day. Significant improvements can be made by reducing the cost of membrane modules and by increasing flux rates obtained. The improvements in system performance obtained in the final task of work are significant and will increase the number of EOR sites where UF systems can provide an economical alternative to conventional treatment technologies.

ABRÉGÉ

Les systèmes d'ultrafiltration à flux en surface qui ont été appliqués avec succès au traitement des huiles émulsifiées dans de nombreuses industries, peuvent offrir une solution de rechange valable au traitement classique des émulsions d'eau produites en champ pétrolifère.

Des échantillons de l'eau produite furent obtenus à différents sites de régénération améliorée des huiles dans l'Ouest du Canada pour être étudiés, afin de déterminer la variabilité qui existe d'un site à l'autre et à différents points du procédé de régénération. Des essais furent ensuite menés à l'aide de cellules d'essai avec membranes à plaques et d'un échantillon d'eau produite en tête de puits, à des températures de 65°C, 75°C et 85°C. Dans ces essais, le flux le plus important fut légèrement supérieur à 1 m^3/m^2/jour et la membrane n'a pas été plus performante aux températures élevées. Un échantillon semblable d'eau produite en tête de puits et contenant un niveau d'huile élevé (1,700 mg/l) fut mis à l'essai à l'aide de modules à membranes tubulaires de 1/2 pouce, avec des niveaux de turbulence plus élevés qu'en cellules à plaques. Des membranes de 6 différentes compositions chimiques furent essayées. Dans ces essais, l'on obtint des débits d'écoulement stables de 5 m^3/m^2/jour avec plusieurs des membranes. Toutes les membranes ont rejeté pratiquement tous les solides et les huiles en suspension, le rejet des substances organiques dissoutes variant d'une membrane à une autre. La formule composite d'un film fin "CHP" fut choisie pour continuer les travaux sur la base de son écoulement stable et de ses propriétés de rejet supérieures.

Une série de treize expériences fut ensuite menée à l'aide de l'eau produite, provenant de huit exploitations différentes de régénération améliorée des huiles dans l'Ouest du Canada, pour établir si les vitesses d'écoulement

élevées et stables obtenues avec l'eau produite à partir du premier site pouvaient être aussi obtenues avec les échantillons provenant d'autres sites et à différents points du procédé de régénération. Les résultats de ces essais ont montré que le système à membranes est très variable d'un site à l'autre, les débits allant de 1 m^3/m^2/jour à plus de 4 m^3/m^2/jour pour des échantillons provenant de sites différents. La performance du système à membranes ne semble pas tant liée au niveau des huiles présentes qu'à la stabilité de l'émulsion.

Une dernière série d'essais furent menés pour optimiser un certain nombre de facteurs affectant la performance du système y compris les membranes utilisées, la stratégie opératoire utilisée pour produire l'eau et la composition chimique de l'eau produite elle-même. Ces essais ont montré que sur des échantillons dont les vitesses d'écoulement précédentes étaient faibles, des changements de performance significatifs sont possibles en utilisant des moyens simples comme l'optimisation de la formule de la membrane, l'augmentation du pH de l'eau alimentée en régénération et l'augmentation de la température de service. Ces essais ont suggéré aussi que pour une installation d'échelle normale, il serait préférable que le différentiel de pression de part et d'autre de la membrane soit inférieur.

Du point de vue économique, il a été montré que le coût du traitement avec système d'ultrafiltration, basé sur le plus cher des trois modules à membranes, est comparable à celui du traitement classique à des débits supérieurs à 3 m^3/m^2/jour. De significatives améliorations peuvent être obtenues en réduisant le coût des modules et en augmentant les débits obtenus. Les améliorations de performances obtenues dans la dernière phase du travail sont significatives et augmenteront le nombre de sites de régénération améliorée des huiles où les systèmes à ultrafiltration peuvent présenter une solution de rechange économique aux technologies classiques.

ACKNOWLEDGMENTS

We wish to express our gratitude to Texaco Canada Resources, Esso Resources Canada, BP Canada, Shell Canada, Husky Oil and Murphy Oil who assisted in this work by providing samples of produced water for testing and information on the production and treatment of produced water.

We also wish to express our thanks to Dr. Brian Farnand and Energy Mines and Resources, CANMET, for providing technical assistance for this work and staff at CANMET/CRL in Devon, Alberta for assistance in testing.

1.0 INTRODUCTION

Enhanced oil recovery operations in Western Canada and elsewhere often employ steam stimulation to enhance oil recoveries from formations containing heavy oil. These steam stimulation operations require large volumes of water for steam generation and injection into the formation and generate large volumes of produced water which is contaminated with oil and other organic compounds as well as inorganic material. Since many recovery operations in Western Canada are located in water short or environmentally sensitive areas, effort has been directed, in recent years, to developing efficient and economic processes for the recycling of the produced water for treatment and reuse as boiler feedwater.

Several enhanced oil recovery (EOR) operations are currently recycling some portion of their produced water using various combinations of conventional treatment. Oil field boiler water requirements dictate that all oil, suspended solids, and hardness must be removed and frequently silica levels must also be reduced. Some sites where highly saline produced water is generated also require a reduction of dissolved solids. The presence of natural or added surfactant material in many produced waters results in very stable oil in water emulsions. The treatment of this produced water at some sites by conventional methods can be difficult as a result of these highly stable emulsions.

The produced fluid from the wellhead contains oil and between 2 and 10 barrels of water per barrel of oil. Some of this water may be present in the oil as a water in oil emulsion while the balance may be a distinct produced water phase containing emulsified oil. The produced fluid is generally treated in a free water knock out (FWKO) tank and high temperature separator (HTS) to separate as much of the oil and water as possible. Water from the FWKO and HTS is generally combined and sent to a skim tank where some residual oil may be removed and recycled back to the recovery process. This water is often disposed of by deep well injection or is sent to further treatment for recycle.

If the water is to be recycled, the effluent from the skim tank is usually treated in an induced gas flotation (IGF) unit and sand filter for the removal of suspended solids and oil as shown in Figure 1-1. Considerable quantities of chemicals must be added to maintain the performance of these units. Once oil and solids are removed the water is sent to a lime softening process for hardness and silica reduction then to ion exchange for removal of residual hardness before being recycled to the boiler.

Problems can be encountered with conventional treatment processes which can be expensive and difficult to operate as a result of the chemicals required and the large number of unit operations. The ideal produced water treatment process would have a simplified flow scheme and would require fewer chemicals.

Cross flow ultrafiltration (UF) processes have been accepted as efficient and economical methods of treating many industrial waste streams containing emulsified oils including cutting oil emulsions. Since UF is a cross flow filtration system and not a dead end filter, as shown in Figure 1-2, it can handle higher oil levels than a sand filter and eliminate the need for the IGF and some of the functions of the skim tank. The UF also provides an absolute barrier smaller than

FIGURE 1 - 1

Conventional Produced Water Treatment Process

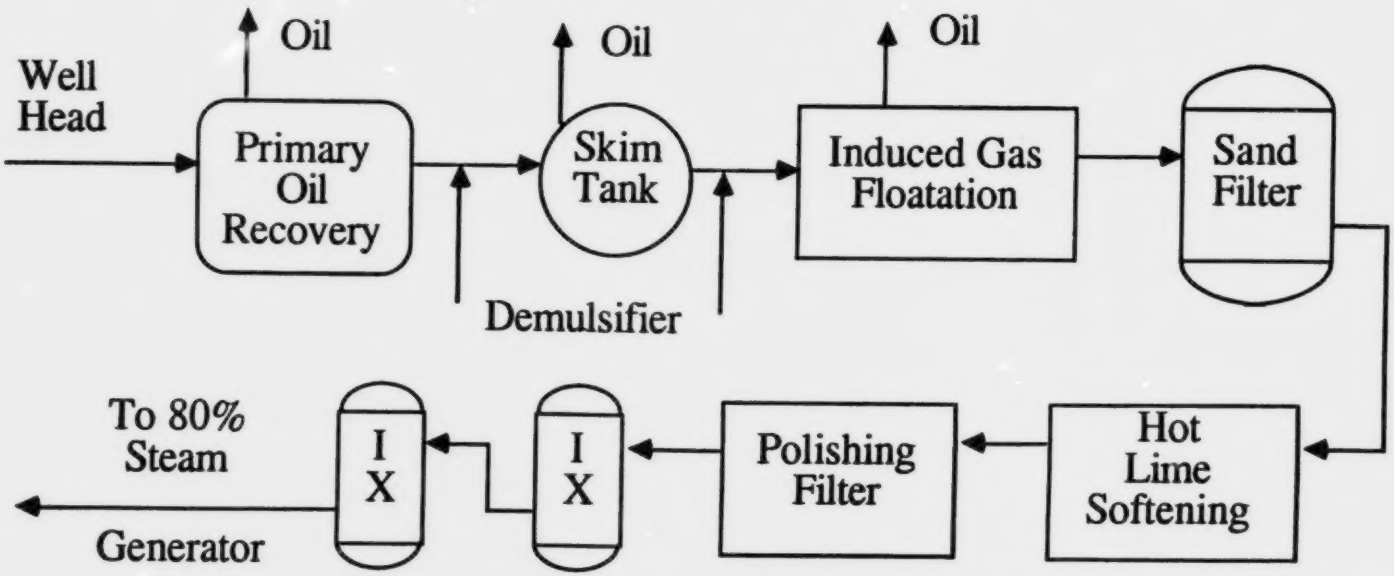
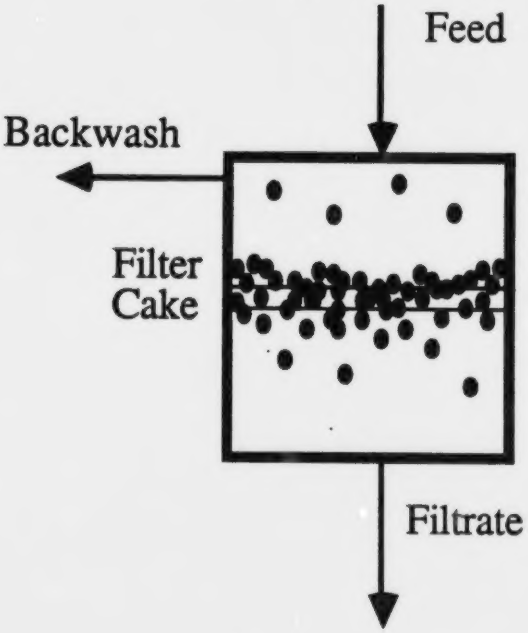

Well Head
Primary Oil Recovery
Oil
Skim Tank
Oil
Demulsifier
Induced Gas Floatation
Oil
Sand Filter
Hot Lime Softening
Polishing Filter
I X
I X
To 80% Steam Generator

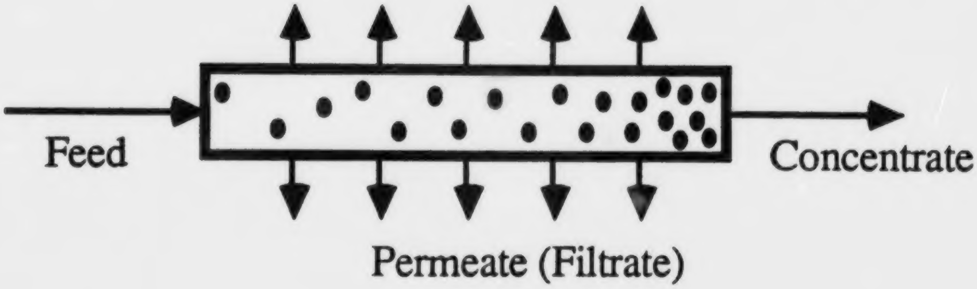
FIGURE 1 - 2

Cross Flow vs Dead End Filtration


Feed
Backwash
Filter
Cake
Filtrate

Dead End Filtration

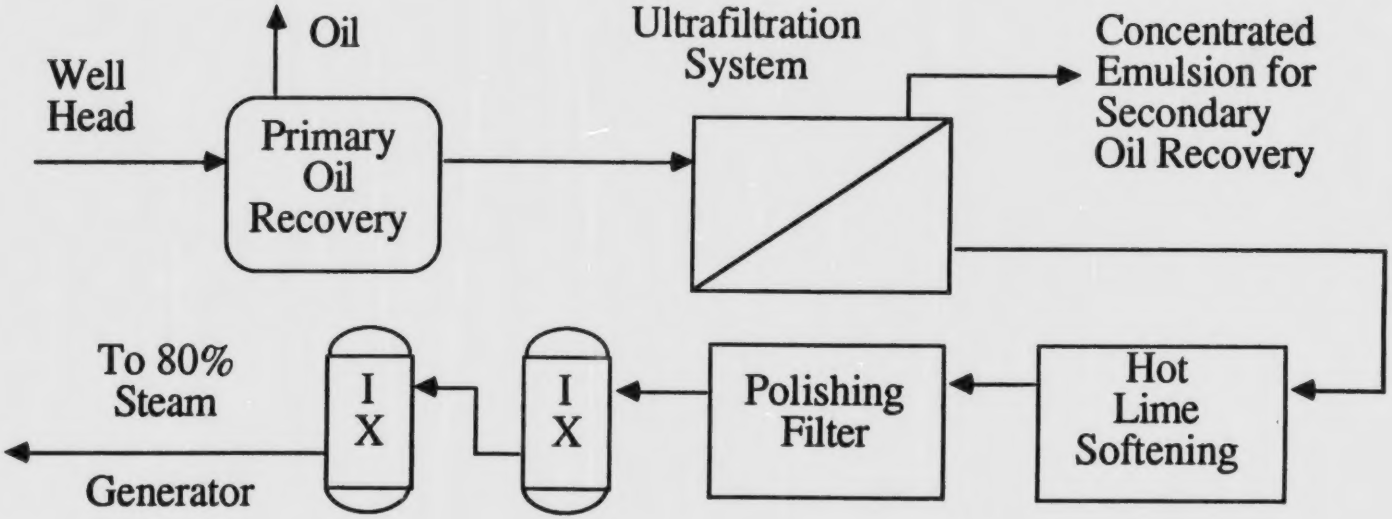
Cross Flow Filtration


Feed
Concentrate
Permeate (Filtrate)

is possible with sand filters resulting in a higher quality filtrate and elimination of oil breakthrough during upset conditions. Figure 1-3 shows how the UF process might fit into the overall produced water treatment process.

Previous work on membrane treatment of oil field produced waters (ZENON 1985) had demonstrated that the process was technically feasible and could be economically feasible as well if flux rates could be maintained at high levels through efficient cleaning, high temperature operation, and improvements in membrane formulations and modules. This work was undertaken to develop and demonstrate the general applicability of methods of improving ultrafiltration membrane system performance by examining these parameters and testing system performance with samples of produced water from several different EOR sites.

FIGURE 1 - 3
Potential Membrane Treatment Process


Well Head
Oil
Primary Oil Recovery
Ultrafiltration System
Concentrated Emulsion for Secondary Oil Recovery
Hot Lime Softening
Polishing Filter
I X
I X
To 80% Steam Generator

2.0 EXPERIMENTAL PROCEDURES

2.1 Initial Sample Characterization

2.1.1 Sample Description

Four, ninety gallon samples of produced water were obtained from insitu heavy oil recovery operations in Western Canada. Two of the samples were obtained from the same heavy oil recovery operation in Alberta referred to as site A. One of these samples was obtained from the effluent of the high temperature separator (HTS) which is used to remove residual water from the bulk of the oil recovered. This sample was uniform throughout and contained a highly coloured water with very little suspended material. The second sample from this site was obtained directly from the wellhead prior to treatment of the fluid for oil recovery. This sample contained a settled oil sludge and some surface oil in addition to the produced water emulsion. The emulsion was separated from the other two phases and transferred to clean barrels for analysis and testing. This sample was dark brown and contained a high level of suspended or emulsified material.

The third sample was obtained from an in-situ pilot operation in Western Canada (site "B"). This sample contained produced water from a simple gravity separation of fluid taken directly from the ground at this site. No chemicals had been used in the treatment of this fluid. Some settled oil and surface sludge was removed to obtain the emulsion. This sample was visually similar to the Site "A" wellhead emulsion.

The fourth sample of produced water was obtained from a pilot EOR operation in Saskachewan (Site "B2"). The sample was of produced fluid as it came out of the ground and contained both heavy oil and produced water. The produced water was decanted off the heavy oil sludge contained at the bottom of the barrel. The produced water contained a small amount of suspended material which, over the course of several weeks coagulated and settled out of the water.

2.1.2 Emulsion Stability

The stability of each of the four produced waters was evaluated by examining the effect of pH, heating, freezing, and demulsifier addition on emulsion stability. These simple tests were performed to provide background on the technical feasibility of alternative processes for emulsion separation.

Effect of pH

In order to determine the stability of the emulsions with respect to pH, samples were pH adjusted to different values with NaOH or H_2SO_4. The pH of 50 mL samples of each of the four emulsions were adjusted to values of 2, 4, 4.5, 5.0, 5.5, 6, 8, 10, and 12. The samples were mixed and allowed to stand for several hours. The degree of separation and quality of supernatant were observed and recorded.

Effect of Freezing

One hundred mL samples of each emulsion were placed in polyethelene containers and put in a freezer for 24 hours. The containers were removed from the freezer and allowed to warm to room temperature. The degree of separation and quality of supernatant obtained were observed and recorded.

Effect of Heating

An aliquot of each emulsion was heated in a boiling water bath for a 1/2 hour period of time. The samples were then allowed to cool and the degree of separation and quality of supernatant obtained were observed and recorded.

Effects of Chemical Demulsifiers

Samples of chemical demulsifiers were obtained from Witco Chemical and demulsifiers RTC 323, and RTC 327 were tested. These products are specified for breaking stable oil in water emulsions and are referred to by Witco as reverse demulsifiers. For the purpose of this report they will be referred to simply as demulsifiers.

Stock dilutions containing 10% by volume of each demulsifier were prepared with tap water and with a 2% ZnCl solution. One mL portions of each of the four solutions were added to beakers containing 100 mL of the produced water emulsions. The contents of the beakers were mixed and then allowed to stand. The degree of separation and quality of the supernatant were observed and recorded. The solutions were further diluted to 2.5% and 0.625% demulsifier in water or ZnCl solution. The ability of these further diluted demulsifiers to break the emulsion was tested in the same manner as before.

2.1.3 Routine Chemical Analysis

The following analyses were conducted on each of the samples of emulsion:

pH,

Turbidity,

Conductivity,

Total Organic Carbon (TOC),

Filtered Organic Carbon (FOC),

Total Suspended Solids (TSS),

Total Suspended Oil (TSO),

Total Dissolved Solids (TDS),

Total Dissolved Oil (TDO),

Anions,

Cations,

Calculated Hardness, and

Dissolved Silica.

The pH, conductivity, FOC, anion scan, cation scan, hardness, and silica measurements were done on samples which had been filtered through a Wattman GF/C filter prior to analysis. The procedures used for these analyses are presented in Appendix A.

2.1.4 Gas Chromatography Analysis

The four samples of emulsion were prepared by back extraction to isolate the acid fraction only before analysis by gas chromatography. The pH of each sample was adjusted to 3 with HCl and then extracted with Dichloromethane. The organic phase was then back extracted with aqueous potassium hydroxide. The aqueous base extracts, containing salts of organic acids, were then reacidified and extracted with dichloromethane to yield the acid fractions in an organic phase. These organic phases were evaporated down before GC analyses. Figure 2-1 shows a summary of the isolation procedure used.

Portions of the samples were then injected into a Hewlett-Packard 5880A gas chromatograph with flame ionization detection for determination of the organic acids present.

2.2 High Temperature Membrane Testing with NRC Cells And Site "A" Wellhead Sample

2.2.1 Apparatus

A membrane testing apparatus was constructed for use in this, and subsequent, membrane testing. A schematic for the test equipment is shown in Figure 2-2. The test equipment used a specially modified type SSF AAC Moyno pump capable of delivering 10 USGPM at 100 psi at temperatures up to 90°C. The rotor of the pump was undersized to compensate for elastomer swelling at high temperatures and an oversized three horse power motor was used to drive the pump.

The pump was fed from a 50 L, 316 stainless steel tank equipped with a cooling jacket for temperature control. An in-line temperature probe near the outlet of the tank sent a signal to the cooling water control valve. A low flow shut off switch was installed on the line between the process tank and pump inlet to protect the pump in case a system leak caused the tank to run dry. A high temperature shut off switch was installed on the outlet line from the pump to protect the system in case of overheating. An in-line probe thermometer on this line was used to monitor system temperature. A bypass line with a needle valve was installed on the line feeding the membrane test cells to maintain the flow to the cells at the desired

FIGURE 2-1

PREPARATION OF PRODUCED WATER SAMPLES FOR GC ANALYSIS

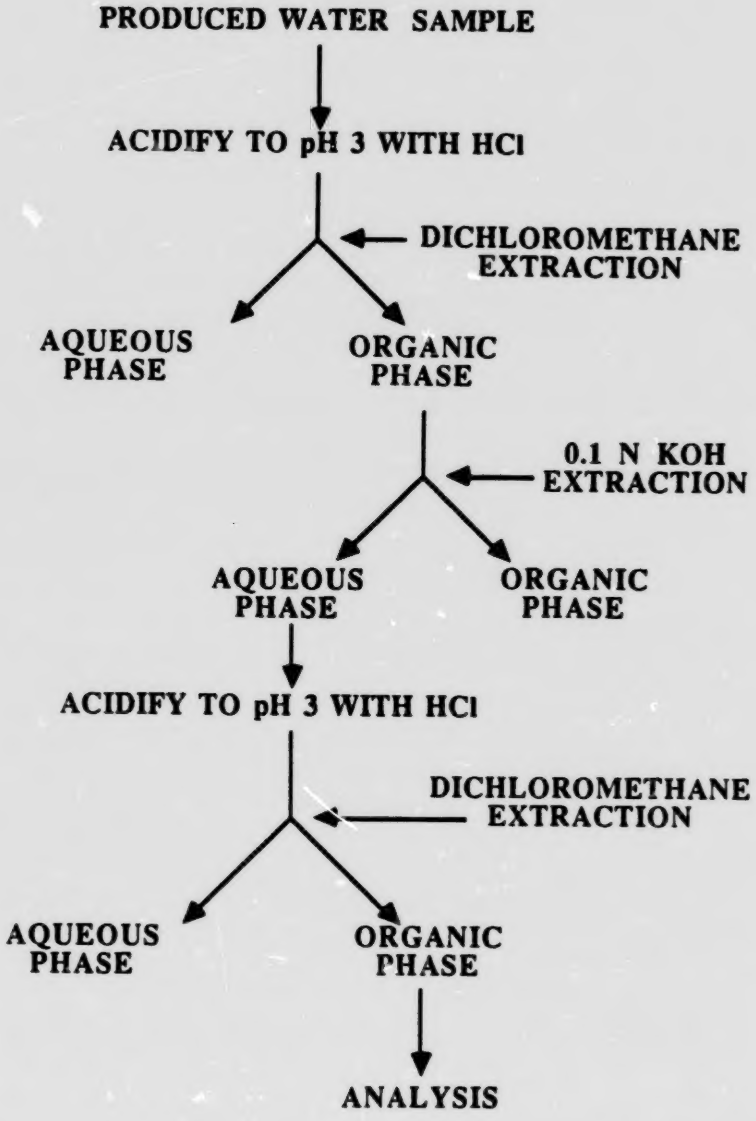
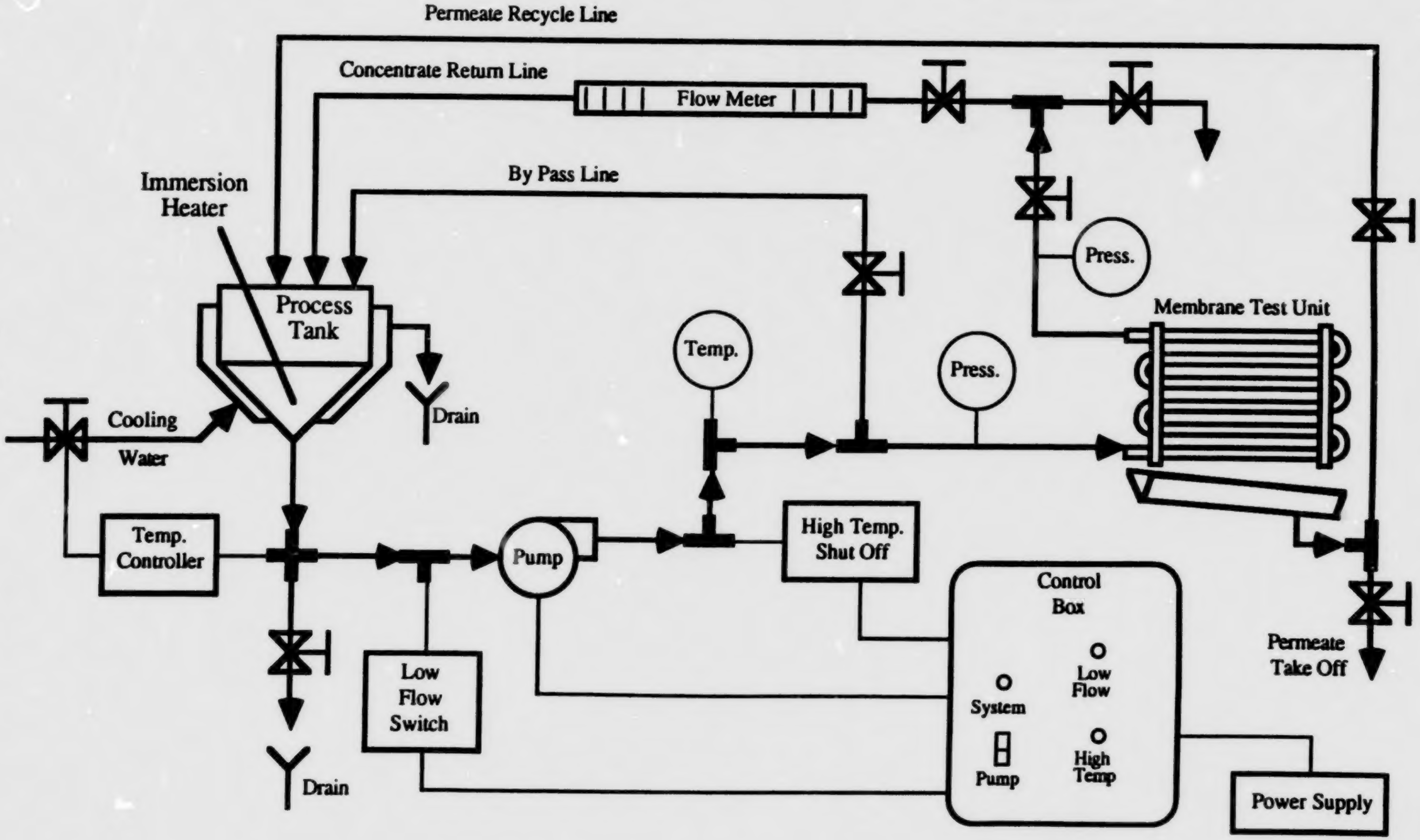

PRODUCED WATER SAMPLE
ACIDIFY TO pH 3 WITH HCl
DICHLOROMETHANE EXTRACTION
AQUEOUS PHASE
ORGANIC PHASE
0.1 N KOH EXTRACTION
AQUEOUS PHASE
ORGANIC PHASE
ACIDIFY TO pH 3 WITH HCl
DICHLOROMETHANE EXTRACTION
AQUEOUS PHASE
ORGANIC PHASE
ANALYSIS

FIGURE 2 - 2

Flow Schematic for Membrane Test Equipment


Permeate Recycle Line
Concentrate Return Line
Flow Meter
By Pass Line
Immersion Heater
Process Tank
Drain
Cooling Water
Temp. Controller
Drain
Low Flow Switch
Pump
Temp.
High Temp. Shut Off
Press.
Press.
Membrane Test Unit
Control Box
System
Pump
Low Flow
High Temp
Permeate Take Off
Power Supply

rate. A pressure gauge on this line just after the bypass line was used to monitor the feed pressure to the cells. The return line was equipped with a back pressure measuring gauge and a needle valve to control this back pressure. Valves were installed on the return line to allow for direct measurement of the flowrate coming out of the test cells. The permeate from the membrane test unit could be collected or recycled back to the process tank.

2.2.2 Procedure

Three high temperature tests were conducted using the NRC cells and seven different membranes. Membranes E500 (polysulfone), G10 (TFC), and CHP CAT (CHP-NN) had been identified as the best membranes for this application in previous work and were used in these tests. The E500 and G10 membranes are commercially available membranes in the USA and the CHP-CAT is manufactured by ZENON water Systems, Inc. According to manufacturers information the E500 membrane has a pore size of 500 Angstroms suggesting a molecular weight cut off above 20,000 while the G10 has a pore size of 10 Angstroms suggesting a molecular weight cut off of less than several thousand. The CAT membrane has a molecular weight cut off of about 20,000. Additional membranes HPC 334, CHP-CA 348, HPC 339, and CHP TFC 346 developed by ZENON for oily water applications were also included in these tests.

For each of the tests, the process tank was filled with approximately 35 - 40 L of the wellhead emulsion which was obtained from Site "A" in early 1984. Fresh samples of this emulsion were used for each of the three tests. The temperature of the emulsion was maintained at 65°C, 75°C or 85°C by adjusting the setting on the cooling water controller for the process tank water jacket. Sufficient heat was provided by the pump for operation at 65°C and 75°C and an imersion heater was used to provide additional heat during the 85°C test. There was no pH adjustment of the emulsion feed.

Each of the tests were run for a period of 24 hours. During that time, the flux rates were monitored on a regular basis and the permeate from each of the membranes was collected and analyzed for the following parameters:

pH,
Conductivity,
Turbidity,
Total Organic Carbon (TOC),
Total Dissolved Solids (TDS),
Hardness,
Calcium,
Magnesium, and
Silica.

Samples of the feed, at the start of the tests and after the tests were complete, were filtered and analyzed for conductivity, filtered organic carbon (FOC), silica, calcium, magnesium, and hardness. Raw samples were analyzed for pH, total dissolved solids (TDS), total dissolved oil (TDO), total suspended solids (TSS), and total suspended oil (TSO). The procedures used for all these analyses are presented in Appendix A.

2.3 Static Membrane Cleaning Tests

2.3.1 Procedure

Small coupons of membranes HPC, CHP-CA, E500, and CHP-TFC from a test at 85°C in the NRC test cells were placed in small beakers containing membrane cleaners MC-4, MC-8, MC-14, MC-5, MC-20, and MC-21 and allowed to soak for a period of about 15 hours. After 15 hours the membranes were removed from the beakers and were brushed several times with a small sponge soaked in the cleaner being tested. The degree of membrane cleaning for each membrane in each cleaner was observed and recorded. Small coupons of the same four membranes from the 65°C test were cleaned in the same manner using cleaners MC-30, 31, 32, 40, 41, and 42. The characteristics of the cleaners used are shown in Table 2-1.

2.4 Tubular Membrane Testing with Site "A" Wellhead Emulsion

2.4.1 Apparatus

The apparatus used for these tests was the same membrane test equipment used during the high temperature tests with the NRC cells. The equipment was modified by placing an in line flowmeter on the outlet line from the membrane test unit to allow for better monitoring and control of the flowrate through the membranes.

A tubular membrane test apparatus as shown in Figure 2-3 was used in place of the NRC cell for the first 5 of these tests. The test unit consisted of 6 one foot sections of 1/2 inch diameter stainless steel tubing set up side by side and supported at either end by metal plates. Tubular membranes are inserted inside the steel tubes and held in place by rubber end seals and end plates. Fresh

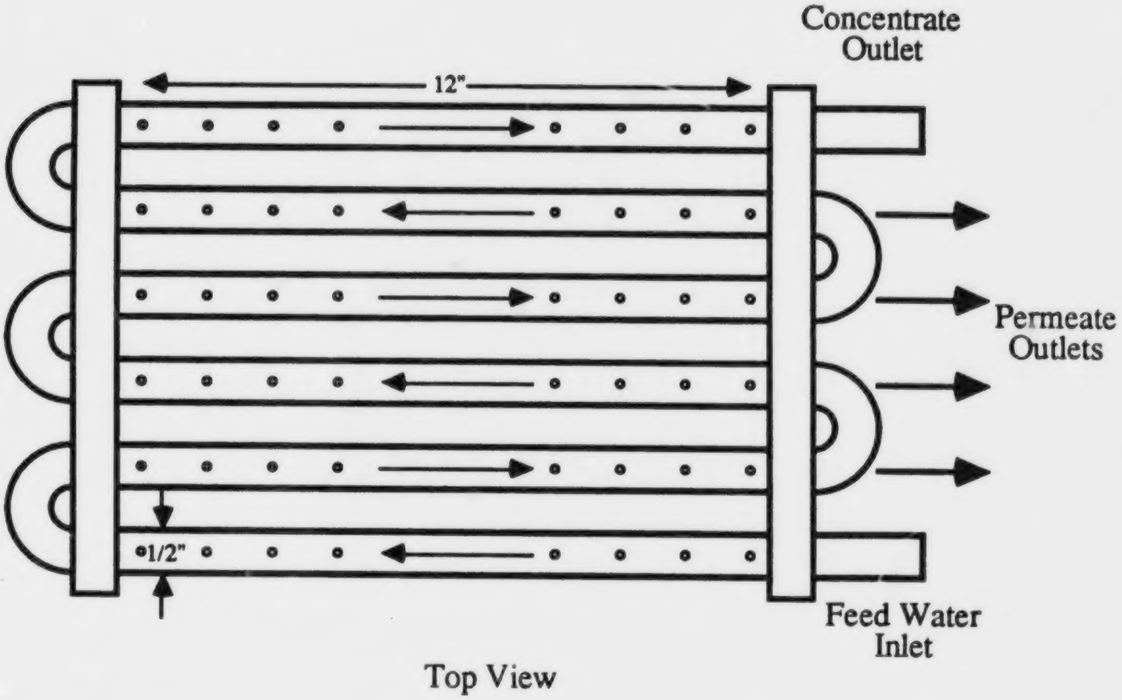
TABLE 2-1

CHARACTERISTICS OF MEMBRANE CLEANERS

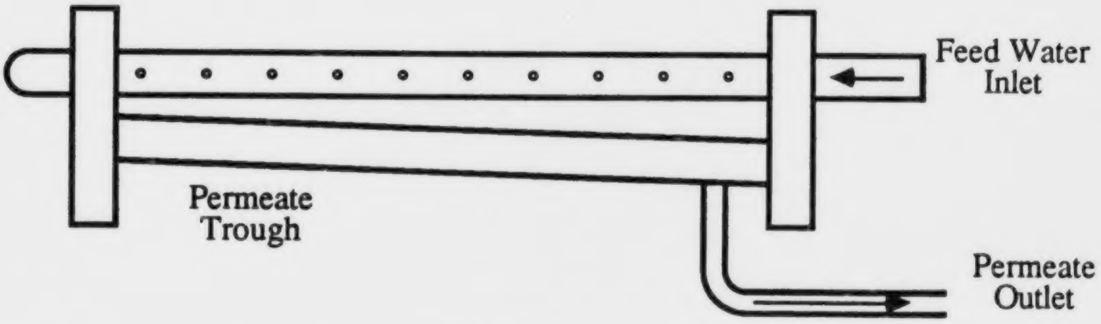
Cleaner	**Composition**
MC-4	anionic surfactant with caustic
MC-5	neutral surfactant
MC-8	enzyme cleaner
MC-14	cationic surfactant
MC-20	solvent activated surfactant
MC-21	solvent activated surfactant
MC-30	anionic surfactant with 10% naptha
MC-31	anionic surfactant with 50% naptha
MC-32	100% naptha
MC-40	anionic surfactant with 10% cyclohexane
MC-41	anionic surfactant with 50% cyclohexane
MC-42	100% cyclohexane

FIGURE 2-3

Tubular Membrane Test Apparatus


Concentrate Outlet
12"
Permeate Outlets
1/2"
Feed Water Inlet

Top View


Feed Water Inlet
Permeate Trough
Permeate Outlet

Front View

feed enters the unit and passes through each of the six tubes in series. Permeate which passes through the membranes flows out of the steel tubes through small holes drilled in the walls of the tubes. The permeate is collected in a V shaped trough under each of the tubes. The support tubes and the permeate collection trough were covered to reduced evaporative losses.

A cleaning system was also constructed to allow for 2 different cleaning solution to be pumped through tubes 1 to 3 and 4 to 6 separately. The cleaning system consisted of two tanks each with a circulation pump feeding the tubes to be cleaned. The lines feeding the tubes also had a "T" fitting to allow for the addition of sponge balls for cleaning. A schematic of the cleaning system is shown in Figure 2-4.

The Polyolefin membrane test was conducted using a somewhat different membrane test unit. This test unit consisted of two 50 cm fiberglass support tubes contained within a clear plastic shell. Membranes are inserted inside in the support tubes which have small holes to allow the passage of permeate. The feed enters one tube then passes through a "U" connector to the second tube. Permeate which passes through the membranes, and out of the support tubes is removed from the plastic shell through a small fitting. An exploded view of the test unit is shown in Figure 2-5.

2.4.2 Procedure

Six tubular membrane tests were conducted using wellhead emulsion obtained from Site "A" in December 1985. The membranes tested included a polyether sulphone (PES), a polyvinyl difluoride

FIGURE 2-4

Cleaning System for Tubular Membranes

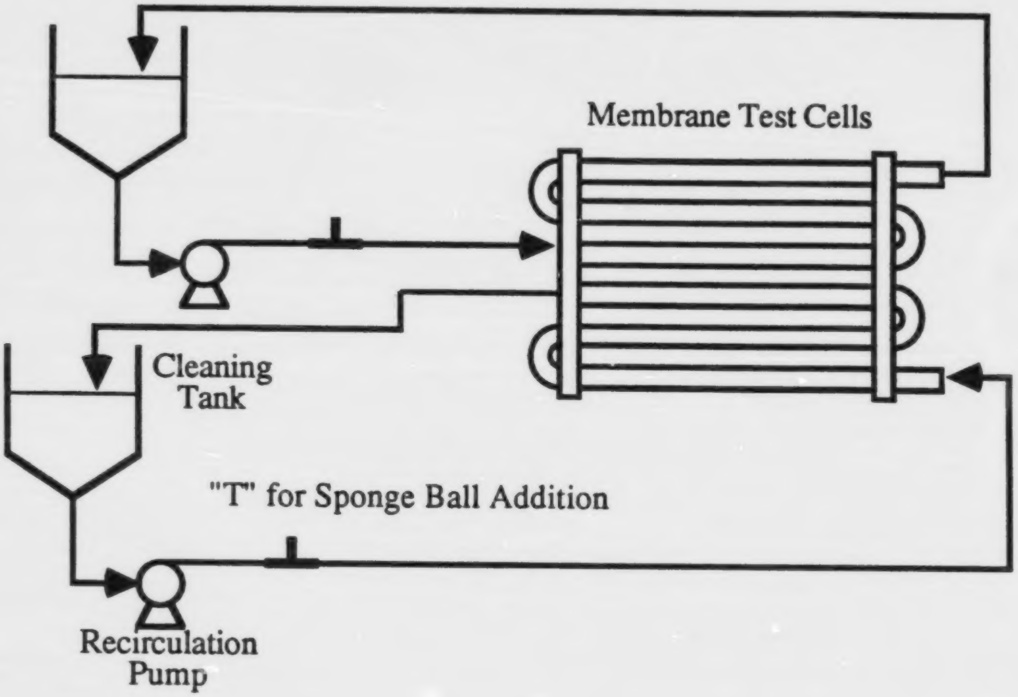
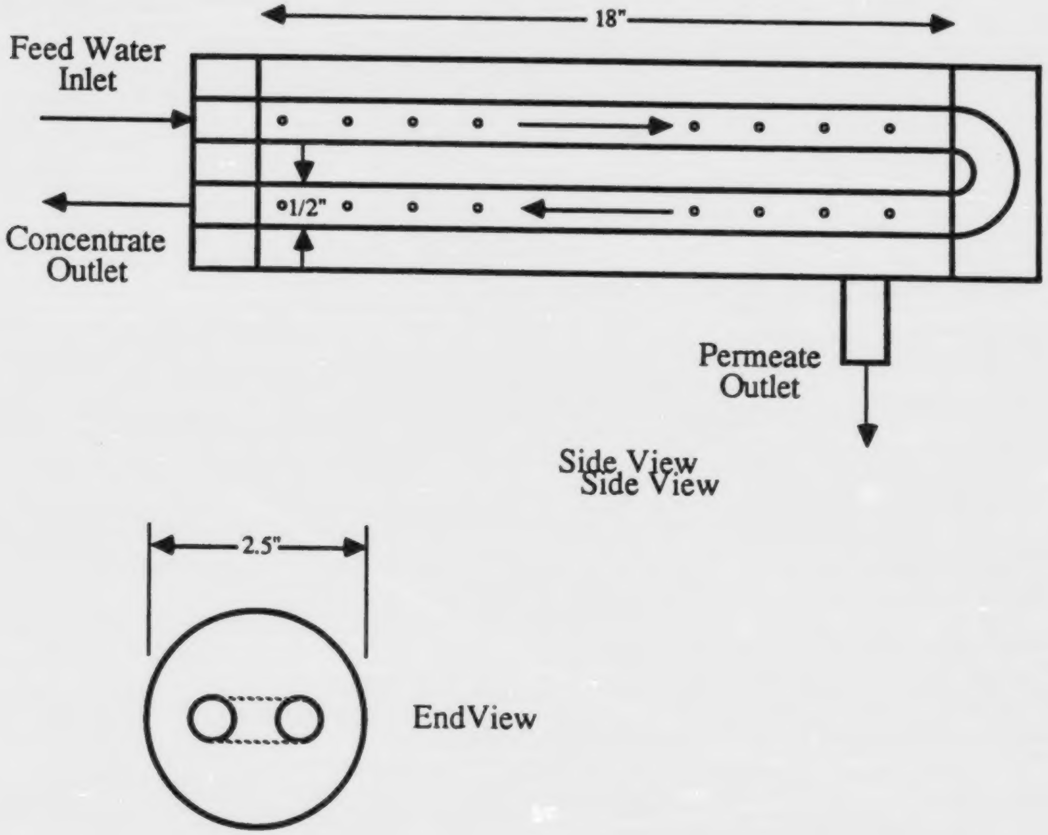

Membrane Test Cells
Cleaning Tank
"T" for Sponge Ball Addition
Recirculation Pump

FIGURE 2 - 5

Membrane Test Module Used for Polyolefin Membrane Test


18"
Feed Water Inlet
Concentrate Outlet
1/2"
Permeate Outlet
Side View
Side View
2.5"
EndView

(PVDF), and a polyolefin (PO) which are commercially available, and a CHP-CA membrane, a CHP-TFC membrane, and a large pore HPC membrane which have been developed at ZENON and have proprietary formulations.

All membrane tests were conducted at 65°C except the polyolefin test which was limited to 50°C as a result of the test module used. The flowrate through the membranes during all tests was 20 L/min. The pressure during all the tests was maintained at 690 kPa(100 psi).

Tests were conducted using an initial volume of 50 L of produced water emulsion. During the initial portion of each test, permeate was collected and the emulsion was allowed to concentrate. After 45 L of permeate had been collected the permeate was then recycled back to the process tank. The system was operated in this mode at a 90% volume reduction (concentration factor of 10) until there was a significant loss in flux (> 30%) or a stable flux was obtained for an extended period of time. Samples of permeate and concentrate were taken at 50% and 90% volume reductions and just prior to membrane cleaning. During the early runs, pure water makeup was added to the process tank as needed to make up for evaporative losses.

Cleaning of membranes was conducted to determine the recovery of flux which could be obtained through cleaning and to see if cleaning causes any changes in the permeate quality. Cleaning solution MC-4 was pumped through membrane tubes 1 to 3 for a period of one hour at low pressure and room temperature. At the same time solvent based cleaners MC-20 or MC-40 were pumped through membrane tubes 4 to 6 under the same conditions. Cleaner MC-20 was used for the first 3 tests and MC-40 was used during the remaining 3. The cleaners were then rinsed from the system with clean water and the system was operated with the concentrated emulsion for several hours to observe the effect of cleaning on flux rate and allow a sample of permeate to be collected. Cleaning was then attempted using the cleaners as before but in combination with sponge balls. Cleaner MC-4 was pumped through membranes 1 - 3 and ten sponge balls were passed through the tubes. Solvent cleaner MC-20 or MC-40 was pumped through tubes 4 - 6 again along with ten sponge balls. The cleaners were then circulated through the tubes for one hour. The system was then operated as before to allow for flux measurements and samples of the permeate to be obtained.

2.5 Tubular and Spiral Membrane Testing with Site "A" HTS Emulsions

2.5.1 Apparatus

The apparatus for these tests was the same membrane test equipment used during previous tests. The tubular membrane tests used the same membrane test apparatus as was used in previous tests. The spiral modules used were 2" in diameter and 12" long and had a membrane area of 4.34 ft^2.

2.5.2 Procedure

One test was conducted using a tubular CHP-TFC membrane and a sample of produced water from the high temperature separator at Site "A". The test procedure was similar to that used for previous tubular membrane testing with the wellhead emulsion. The emulsion was concentrated to a 90% volume reduction or a concentration factor of 10 after which permeate was recycled for an additional 40 hours of operation. The emulsion was then further concentrated to a 95% volume reduction or concentration factor (CF) of 20 and operated for over 24 hours in a recycle mode. At the end of this 24 hour period, cleaning with MC-4 and MC-40 was conducted. Cleaning was also conducted with cleaners MC-4 and MC-40 with sponge balls as in previous tests. Samples of permeate and concentrate were taken at various times to monitor the effect of operating conditions on permeate quality.

A second test was conducted using the same CHP-TFC membrane in a spiral configuration with the same HTS sample. The temperature during the test was 50°C and the transmembrane pressure was 690 kPa (100 psi.) The flow to the spiral module was maintained at 5.68 L/min. During this test the volume of emulsion was reduced by 30% (CF of 1.429) and the system was operated for approximately 23 hours. The emulsion was further concentrated to a 60% volume reduction or a CF of 2.5. After 20 hours of recycle at this concentration, cleaning was conducted using cleaner MC-40 for 1 hour at room temperature. The system was operated again and was subjected to two more cleaning cycles before termination of the run.

A third test was conducted using a smaller pore spiral CHP-TFC membrane with permeate which had been collected during tests with HTS emulsion and the larger pore CHP-TFC membrane. During this test, the feed was concentrated to a CF of 10 during the first few hours of operation then operated at this level for a period of 24 hours. The system was then subjected to three cleaning cycles with cleaner MC-40, MC-4, then MC-40 once again. The system was operated for approximately 24 hours between cleaning to determine the stability of the flux rate.

2.6 Long Term Testing with Different Emulsions

2.6.1 Apparatus

The apparatus for this testing was the same as was used in previous testing with the one half inch tubular membrane module.

2.6.2 Procedure

Seven longer term tests were performed using produced water samples obtained from six different heavy oil production sites in Western Canada. The produced water was concentrated to a 90% volume reduction and the system was then in this mode for a period of one to two weeks. Cleaning of the membranes was conducted as necessary to maintain the flux rates at high levels. Analysis was conducted on the initial feed, on concentrates and permeates at the final level of volume reduction and permeates after cleaning. The membranes used throughout these tests were CHP-TFC and a slightly modified version of this membrane, PSC-C.

2.7 Testing with Different Emulsions at Devon, Alberta

2.7.1 Apparatus

The apparatus used for this test work was the same as was used in previous testing with the one half inch tubular membrane module.

2.7.2 Procedure

Five tests were performed using produced water samples obtained from different heavy oil production sites in Western Canada.

Two of the samples were obtained from different steps in the produced water treatment from the same EOR site.

The time lag between sample collection and testing was reduced to two or three days by operating the test unit in Western Canada.

The produced water was generally concentrated by a factor of 10 and the system was operated in this mode with the permeate recycled to the feed tank for an extended period of time. Cleaning of the membranes was conducted as necessary. The membranes used throughout these tests were a slightly modified formulation of the PSC-C membrane, FLT-C.

Analysis was conducted on the initial feed and on concentrates and permeates at the final level of volume reduction and the permeate after cleaning.

2.8 In House Process Optimization

2.8.1 Apparatus

The apparatus used for this test work was the same as was used in previous testing with the one half inch tubular membrane module.

2.8.2 Procedure

A series of tests were conducted using produced water samples from three different sites in Western Canada.

The operating procedures used during these tests involved operation at pressures of 345, 517 and 690 kPa (50, 75, and 100 psi) with the FLT-C membrane previously used and other membranes recently developed for oily water applications. Testing was also done at higher operating temperatures and with higher system flowrates to determine the effect of changing these operating parameters. Tests were also conducted to simulate several batch concentration cycles with the same set of membranes.

3.0 RESULTS AND DISCUSSION

3.1 Sample Characterization

3.1.1 Emulsion Stability

Effect of pH

Samples of HTS effluent from site "A" showed no sign of destabilizing at pH values between 10 and 4.5. At a pH of 4 some coalescing and settling of oil occurred but the supernatant remained slightly cloudy. At a pH of 2 the oil coalesced immediately and settled out to produce a clear supernatant.

Samples of the Wellhead emulsion showed no sign of destabilization at pH values between 10 and 4.0. At a pH of 3 some coalescing and settling occurred but the supernatant remained cloudy. At a pH of 2 coalescing and settling occurred but the supernatant again remained somewhat cloudy.

Samples of wellhead emulsion from Site "B" showed no effects of changing the pH to values between 10 and 4.5. At pH 4 very slight destabilization and coalescing occurred but not enough to cause significant settling of oil. At a pH of 3 particles formed and floated to the top of the sample while the remainder of the emulsion remained cloudy. At a pH of 2 particles formed and floated while the emulsion remained slightly cloudy.

Over the course of several weeks the sample of produced water emulsion from Site "B2" destabilized and formed particles which settled without any changes in pH.

Effect of Freezing

After freezing and thawing Site "A" HTS water showed obvious floc formation and settling of suspended oil leaving a relatively clear supernatant. Site "A" wellhead emulsion also showed floc formation and settling but the supernatant contained some suspended particles which did not flocculate.

The sample of Site "B" wellhead emulsion showed some flocculation after freezing but not enough to result in significant amounts of separation.

Freezing of the Site "B2" sample caused no changes since the suspended material present had already flocculated and settled.

Effect of Heating

The two samples from Site "A" showed no visible changes during or after heating. The sample from Site "B" showed signs of a surface oil layer forming during heating. This layer dissappeared after the emulsion cooled.

Suspended material which had settled in the Site "B2" sample floated on the surface when the sample was heated. It is known that the densities of heavy oil and water will change in different ways upon heating. This sample showed graphically how the oil can be more dense than water at ambient temperatures but shift to being less dense than water at higher temperatures. The Site "A" test results demonstrate the stability the emulsions.

Effect of Chemical Demulsifiers

The results of the tests examining the effect of chemical demulsifiers on the four produced waters samples are shown in Table 3-1.

The results demonstrate how the demulsifier used and conditions of demulsification will affect different emulsion samples in different ways. The RTC 323 demulsified the Site "A" and Site "B" emulsions at high concentrations when used alone but operated successfully only at low concentrations when complexed with zinc chloride.

3.1.2 Routine Chemical Analysis

The results of the routine chemical analysis on the 4 emulsions are shown in Table 3-2.

The results show the Site "A" wellhead emulsion to be similar to the Site "A" wellhead emulsion used in previous work obtained in early 1984. The suspended oil level in the new sample (658 mg/L) is somewhat lower than that in the early emulsion (1580 mg/L) and the TDS level is about double (1386 mg/L in the 1985 sample vs 784 mg/L in the 1984 one). These variations are small when compared to the differences in other samples obtained from different locations and process effluents.

The Site "A" HTS effluent as expected had a considerably lower suspended oil level than the wellhead emulsion, 73 vs. 658 mg/L. It was thought that this lower oil level may make treatment with membranes easier than it is with the higher oil wellhead emulsion.

TABLE 3-1

EFFECTS OF CHEMICAL DEMULSIFIERS ON BITUMEN EMULSION

DEMULSIFIER	CONCENTRATION	COMMENTS (see next page)
	Site "A" HTS Water	
RTC 323	1000 ppm	1
	400 ppm	1
	62-5 ppm	4
RTC 323 + ZnCl	1000 ppm	2
	400 ppm	1
	62.5 ppm	1
RTC 327	1000 ppm	1
	400 ppm	1
	62.5 ppm	3
RTC 327 + ZnCl	1000 ppm	3
	400 ppm	1
	62.5 ppm	1
	Site "A" Wellhead Produced Water	
RTC 323	1000 ppm	1
	400 ppm	1
	62.5 ppm	4
RTC 323 +ZnCl	1000 ppm	4
	400 ppm	1
	62.5 ppm	1
RTC 327	1000 ppm	1
	400 ppm	1
	62.5 ppm	3
RTC 327 + ZnCl	1000 ppm	3
	400 ppm	1
	62.5 ppm	1

Continued on next page

TABLE 3-1 Continued

DEMULSIFIER	CONCENTRATION	COMMENTS
Site "B" Wellhead Produced Water		
RTC 323	1000 ppm	1
	400 ppm	1
	62.5 ppm	1
RTC 323 + ZnCl	1000 ppm	4
	400 ppm	2
	62.5 ppm	1
RTC 327	1000 ppm	2
	400 ppm	2
	62.5 ppm	2
RTC 327 + ZnCl	1000 ppm	2
	400 ppm	2
	62.5 ppm	2

Site "B2" wellhead produced water flocs of oil formed with time with no demulsifier addition.

COMMENTS

1. Floc of oil form and settle. Supernatant is clear but coloured.

2. Flocs of oil form and settle. Supernatant remains cloudy.

3. Some floc formation but no significant separation.

4. No effect on oil emulsion.

TABLE 3-2

RAW FEED CHARACTERISTICS

PARAMETER	SITE A WELLHEAD 1984	SITE A HTS 1985	SITE A WELLHEAD 1985	SITE B WELLHEAD	SITE B2 WELLHEAD
pH	8.01	7.65	8.05	7.96	7.35
TOC (mg/L)	1560	320	895	2100	135
FOC (mg/L)	260	240	260	103	135
TDS (mg/L)	716	1528.3	1386.2	2205	9370
TDO (mg/L)	124	390	383.8	276.7	475
TSO (mg/L)	1580	72.7	658	1738	6.7
TSS (mg/L)	40	25.3	26.7	52	82.6
SILICA (mg/L)	100	104	102	84	48
HARDNESS (mg/L)	3.93	30.21	20.97	79.37	487.55
CONDUCTIVITY (umho)	N/A	2.02	1.92	3.00	13.89
TURBIDITY (NTU)	1150	56	900	6700	6
NAPHTHENIC ACID (mg/L)	60	112	11	70	4
ANIONS					
BROMIDE (mg/L)	N/A	<0.3	<0.3	3.3	13
FLUORIDE (mg/L)	4.13	4.9	4.8	2.8	<0.04
CHLORIDE (mg/L)	142	570	510	850	6300
NITRITE (mg/L)	N/A	<0.08	<0.08	<0.08	<0.08
PHOSPHATE (mg/L)	<10	0.84	<0.3	<0.3	<0.3
NITRATE (mg/L)	<.5	<0.08	<0.08	0.09	<0.08
SULPHATE (mg/L)	66.7	68	66	360	24
CATIONS					
BERYLLIUM (mg/L)	<.0005	<0.01	<0.01	<0.01	<0.005
MOLYBDENUM (mg/L)	<.2	0.06	0.08	0.03	0.04
CALCIUM (mg/L)	1.16	8.8	5.3	20	98
VANADIUM (mg/L)	0.012	0.04	0.19	0.16	0.01
ALUMINUM (mg/L)	1.22	0.52	0.55	0.33	0.36
MAGNESIUM (mg/L)	0.25	2	1.88	7.15	59
BARIUM (mg/L)	0.011	0.05	0.04	0.19	7.7
POTASIUM (mg/L)	6	13.5	14.1	64	154
STRONTIUM (mg/L)	0.01	0.4	0.3	1.26	7.9
SODIUM (mg/L)	245	430	450	640	3400
ZINC (mg/L)	<.05	0.12	0.04	0.05	0.01
CADIUM (mg/L)	<.01	0.01	0.02	0.09	<0.005
MANGANESE (mg/L)	0.02	0.04	0.02	0.06	0.49
COBALT (mg/L)	<.05	<0.02	<0.02	<0.02	<0.01
COPPER (mg/L)	0.073	0.01	0.02	0.03	0.01
SILVER (mg/L)	<0.005	<0.02	<0.02	<0.02	<0.01
IRON (mg/L)	7.92	0.36	0.36	0.57	14.3
LEAD (mg/L)	<.05	0.1	<0.02	0.04	0.04
CHROMIUM (mg/L)	<.01	0.02	0.02	<0.01	<0.01
NICKEL (mg/L)	<.05	<0.02	0.01	0.09	<0.01

TOC	TOTAL ORGANIC CARBON	TSO	TOTAL SUSPENED OILS
FOC	FILTERED ORGANIC CARBON	TSS	TOTAL SUSPENDED SOLIDS
TDS	TOTAL DISSOLVED SOLIDS	TDO	TOTAL DISSOLVED OILS

The Site "B" wellhead emulsion had more of most contaminants as compared to the Site "A" wellhead emulsion (TDS of 2205 mg/L vs. 1386 mg/L; TSO of 1738 mg/L vs. 658 mg/L; and hardness 79 mgL vs. 21 mg/L).

The sample of emulsion from Site "B2" initially looked like a stable emulsion containing a lower oil level than the other emulsions. In time however, the oil in the emulsion coagulated and settled with no treatment of any kind.

3.1.3 Gas Chromatography Analysis

The results of the GC analysis on the isolated acid fractions are presented in Table 3-2 along with the results of other analysis. The values for extractable organic acids in the Site "A" HTS water and wellhead emulsion are 112 mg/l and 11 mg/l respectively. The wellhead emulsion is extremely stable despite the low value for naphthenic acid.

Analyses of the previous sample of wellhead emulsion from Site "A" showed 60 mg/l of organic acid. The organic acid concentration in the stable Site "B" emulsion was 70 mg/l while the organic acid concentration in the sample from Site "B2" which broke spontaneously was only 4 mg/l.

3.2 High Temperature Membrane Testing in NRC Cells (Site "A" Wellhead)

The flux rates for the three high temperature tests are shown in Figure 3-1, 3-2, and 3-3. Table 3-3, 3-5, and 3-7 show the results of the analysis of the feeds and permeates for each of the

FIGURE 3-1

Flux Rates for Run #1 (65 °C)

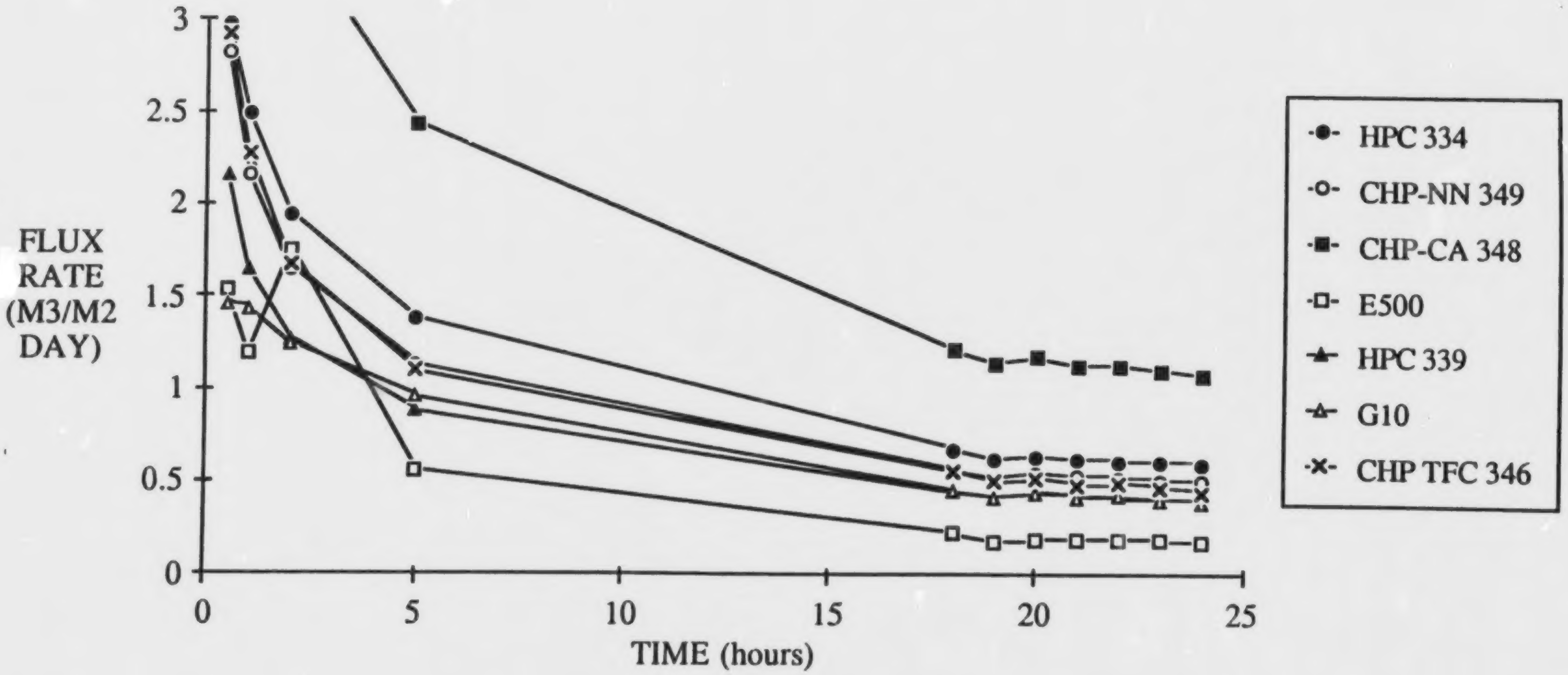


FIGURE 3-2

Flux Rates for Run #2 (75 °C)

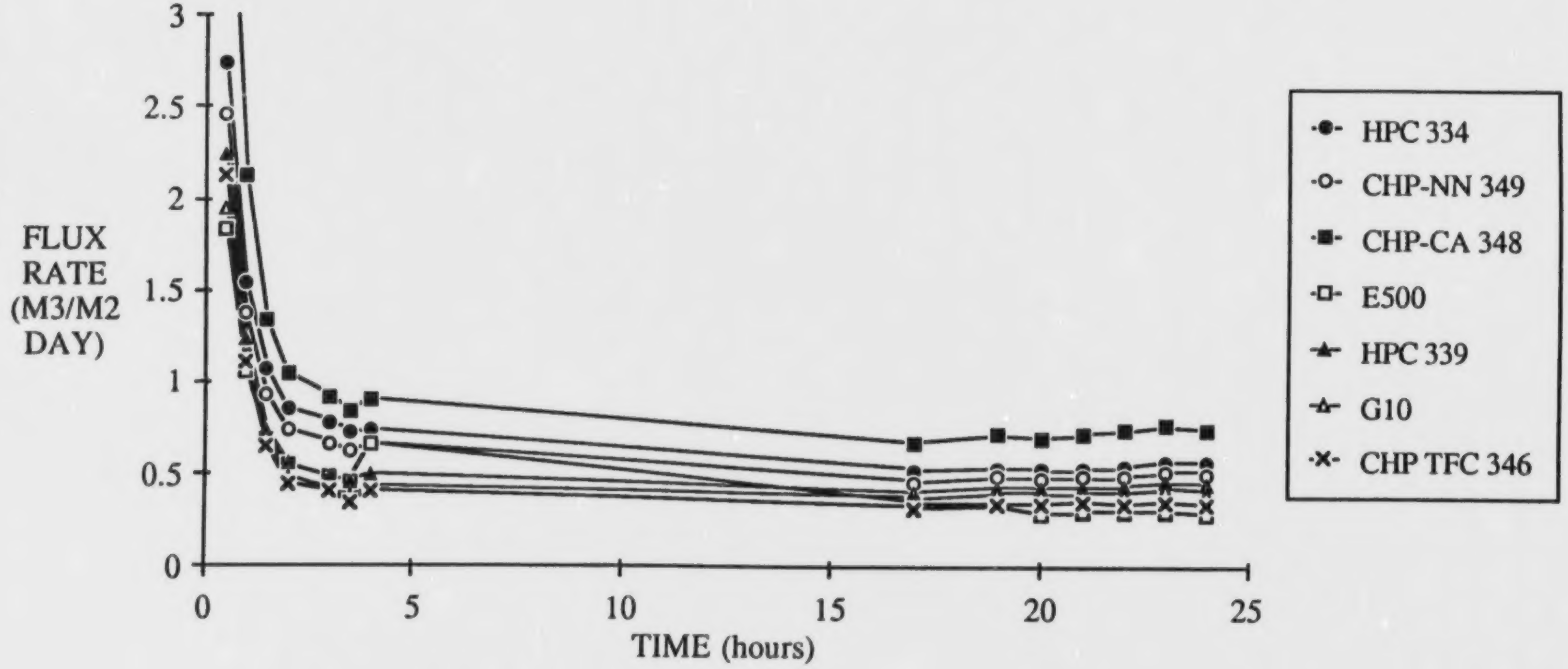


FIGURE 3-3

Flux Rates for Run #3 (85 °C)

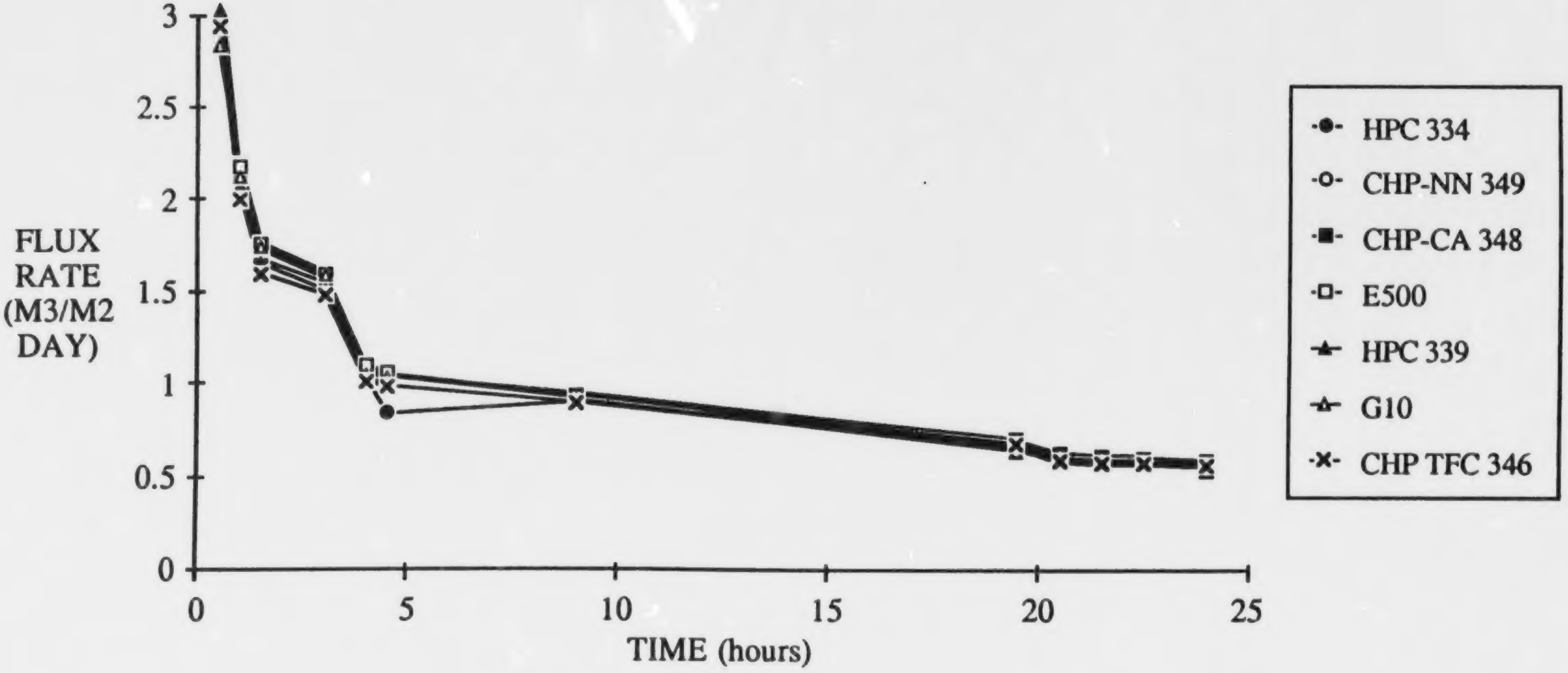


TABLE 3-3

ANALYTICAL DATA FOR SCREENING TEST #1 (65 °C)

PARAMETER	UNITS	INITIAL FEED	FINAL FEED	MEAN FEED	HPC-LS #334 PERM.	CHP-NN #349 PERM.	CHP-CA #348 PERM.	E500 PERM.	HPC #339 PERM.	G10 PERM.	CHP-TFC #346 PERM.
pH		8.70	8.83	8.77	7.96	7.94	7.87	7.98	8.04	7.97	7.90
COND.	umho	1.01	1.08	1.04	0.41	0.41	0.40	0.42	0.43	0.32	0.42
TURB.	NTU	820.00	1720	1270	0.60	0.72	0.54	0.80	0.57	0.62	0.68
TOC	mg/L	140.00	164.00	152.00	45.50	46.00	41.00	59.00	49.00	27.00	44.00
TDS	mg/L	1235.00	1570	1403	220.00	209.30	194.70	201.30	204.00	109.30	206.70
CALCIUM	mg/L	3.20	4.37	3.79	0.16	1.65	0.15	0.24	0.15	1.61	0.13
MAGNESIUM	mg/L	0.78	1.15	0.96	0.03	0.13	0.04	0.05	0.03	0.13	0.03
HARDNESS	mg/L	11.20	15.63	13.42	0.53	4.65	0.51	0.79	0.48	4.56	0.45
SILICA	mg/L	40.00	54.00	47.00	31.00	31.00	31.00	31.00	31.00	27.00	31.00
TSS	mg/L	1410	1500	1455	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3-4

PERCENT REJECTION OF MONITORED CRITERIA

PARAMETER	HPC LS #334 % REJ.	CHP NN #349 % REJ.	CHP CA #348 % REJ.	E500 % REJ.	HPC #339 % REJ.	G10 % REJ.	CHP TFC #346 % REJ.
COND.	61%	61%	62%	60%	59%	69%	60%
TURB.	100%	100%	100%	100%	100%	100%	100%
TOC	70%	70%	73%	61%	68%	82%	71%
TDS	84%	85%	86%	86%	85%	92%	85%
CALCIUM	96%	57%	96%	94%	96%	57%	96%
MAGNESIUM	96%	86%	96%	95%	97%	86%	97%
HARDNESS	96%	65%	96%	94%	96%	66%	97%
SILICA	34%	34%	34%	34%	34%	43%	34%
TSS	100%	100%	100%	100%	100%	100%	100%

TABLE 3-5

ANALYTICAL DATA FOR SCREENING TEST #2 (75 °C)

PARAMETER	UNITS	INITIAL FEED	FINAL FEED	MEAN FEED	HPC-LS #334 PERM.	CHP-NN #349 PERM.	CHP-CA #348 PERM.	E500 PERM.	HPC #339 PERM.	G10 PERM.	CHP-TFC #346 PERM.
pH		8.55	8.71	8.63	7.89	7.90	7.78	7.89	8.00	7.88	8.10
COND.	umho	0.99	1.22	1.11	0.43	0.43	0.41	0.44	0.43	0.37	0.46
TURB.	NTU	820.00	1320	1070	0.63	0.68	0.60	0.70	0.76	0.62	0.77
TOC	mg/L	140.00	144.00	142.00	53.00	58.00	43.00	53.00	58.00	48.00	44.00
TDS	mg/L	1235.00	1450	1343	265.30	266.70	246.70	265.30	272.00	213.30	274.70
CALCIUM	mg/L	3.20	2.62	2.91	0.24	0.73	0.17	0.98	0.16	0.29	0.18
MAGNESIUM	mg/L	0.78	1.25	1.02	0.03	0.06	0.03	0.09	0.03	0.05	0.03
HARDNESS	mg/L	11.20	11.69	11.45	0.74	2.07	0.53	2.82	0.52	0.91	0.59
SILICA	mg/L	40.00	54.00	47.00	28.00	28.00	28.00	28.00	28.00	25.00	30.00
TSS	mg/L	1410	1876	1643	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3-6

PERCENT REJECTION OF MONITORED CRITERIA

PARAMETER	HPC LS #334 % REJ.	CHP NN #349 % REJ.	CHP CA #348 % REJ.	E500 % REJ.	HPC #339 % REJ.	G10 % REJ.	CHP TFC #346 % REJ.
COND.	61%	61%	63%	60%	61%	66%	59%
TURB.	100%	100%	100%	100%	100%	100%	100%
TOC	63%	59%	70%	63%	59%	66%	69%
TDS	80%	80%	82%	80%	80%	84%	80%
CALCIUM	92%	75%	94%	66%	95%	90%	94%
MAGNESIUM	97%	94%	97%	91%	97%	95%	97%
HARDNESS	94%	82%	95%	75%	95%	92%	95%
SILICA	40%	40%	40%	40%	40%	47%	36%
TSS	100%	100%	100%	100%	100%	100%	100%

TABLE 3-7

ANALYTICAL DATA FOR SCREENING TEST #3 (85 °C)

PARAMETER	UNITS	INITIAL FEED	FINAL FEED	MEAN FEED	HPC-LS #334 PERM.	CHP-NN #349 PERM.	CHP-CA #348 PERM.	E500 PERM.	HPC #339 PERM.	G10 PERM.	CHP-TFC #346 PERM.
pH		8.63	8.90	8.77	7.98	7.88	7.93	8.00	7.90	8.00	8.01
COND.	umho	1.11	1.40	1.26	0.51	0.50	0.50	0.51	0.43	0.42	0.52
TURB.	NTU	820.00	1740	1280	0.63	0.65	0.99	0.58	0.63	0.30	0.74
TOC	mg/L	140.00	210.00	175.00	59.00	82.00	94.00	60.00	64.00	30.00	53.50
TDS	mg/L	1235.00	1840	1538	325.30	302.70	308.00	345.30	332.00	233.30	348.00
CALCIUM	mg/L	3.20	2.87	3.04	0.073	0.045	0.130	0.039	0.871	0.044	0.259
MAGNESIUM	mg/L	0.78	0.79	0.78	0.010	0.001	0.007	0.001	0.067	0.001	0.014
HARDNESS	mg/L	11.20	10.40	10.80	0.223	0.116	0.353	0.101	2.451	0.114	0.704
SILICA	mg/L	40.00	64.00	52.00	31.00	31.00	31.00	31.00	31.00	27.00	31.00
TSS	mg/L	1410	1966.7	1688	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3-8

PERCENT REJECTION OF MONITORED CRITERIA

PARAMETER	HPC LS #334 % REJ.	CHP NN #349 % REJ.	CHP CA #348 % REJ.	E500 % REJ.	HPC #339 % REJ.	G10 % REJ.	CHP TFC #346 % REJ.
COND.	59%	60%	60%	59%	65%	66%	59%
TURB.	100%	100%	100%	100%	100%	100%	100%
TOC	66%	53%	46%	66%	63%	83%	69%
TDS	79%	80%	80%	78%	78%	85%	77%
CALCIUM	98%	99%	96%	99%	71%	99%	91%
MAGNESIUM	99%	100%	99%	100%	91%	100%	98%
HARDNESS	98%	99%	97%	99%	77%	99%	93%
SILICA	40%	40%	40%	40%	40%	48%	40%
TSS	100%	100%	100%	100%	100%	100%	100%

three tests. Tables 3-4, 3-6, and 3-8 show the percent rejection of the relevant contaminants for each of the membranes during the membranes testing. Complete results of these tests are presented in Appendix B.

The flux rates observed for membranes E500, G10, and CHP-NN 349 (CHP Cat) during the first run at 65°C were similar to the results obtained during the equivalent test in previous work but were consistently lower for all three membranes. In previous work, flux rates for E500, G10, and CHP were: 1.075, 0.925, and 0.81 m^3/m^2d. During this work they were 0.2, 0.425, and 0.5. These lower flux rates may have been the result of changes in the emulsion while it aged over the year between tests or may be related to unsteady flow in the NRC cells.

Several of the new membranes included in this test exhibited high flux rates relative to the E500, G10, and CHP Cat. Membrane CHP-CA 348 in particular had an extremely high flux of 1.1 m^3/m^2d; over double that of any of the other membranes in this test. Membrane HPC 334 also had a somewhat higher flux rate than any of the other membranes.

The flux rates observed during the run at 75°C were consistently lower for all membranes except the E500 which showed a very slight increase in flux at the higher temperature. During this run, some problems were encountered maintaining the flowrate through the test cells constant at 2 L/min. Some plugging occurred in the NRC cells which resulted in increased backpressure and a decrease in flow. At the end of 17 hours of operation after the system had been left overnight, the flow rate had decreased to near 0.5 L/min. It is believed that this decreased flow and therefore lower level of turbulence in the cell contributed to the lower of flux.

At the highest temperature of 85°C the flux rates for all membranes were identical at slightly greater than 0.5 m^3/m^2d. It was anticipated that the higher temperature would result in higher flux rates but this was not observed. The identical flux rates suggest that the rates are gel layer limited in this situation. It is believed that the nature of the oil in the emulsion changes at higher temperatures resulting in more severe gel layer formation.

In the NRC cell configuration, there does not appear to be any advantage in operating at temperatures above 65°C.

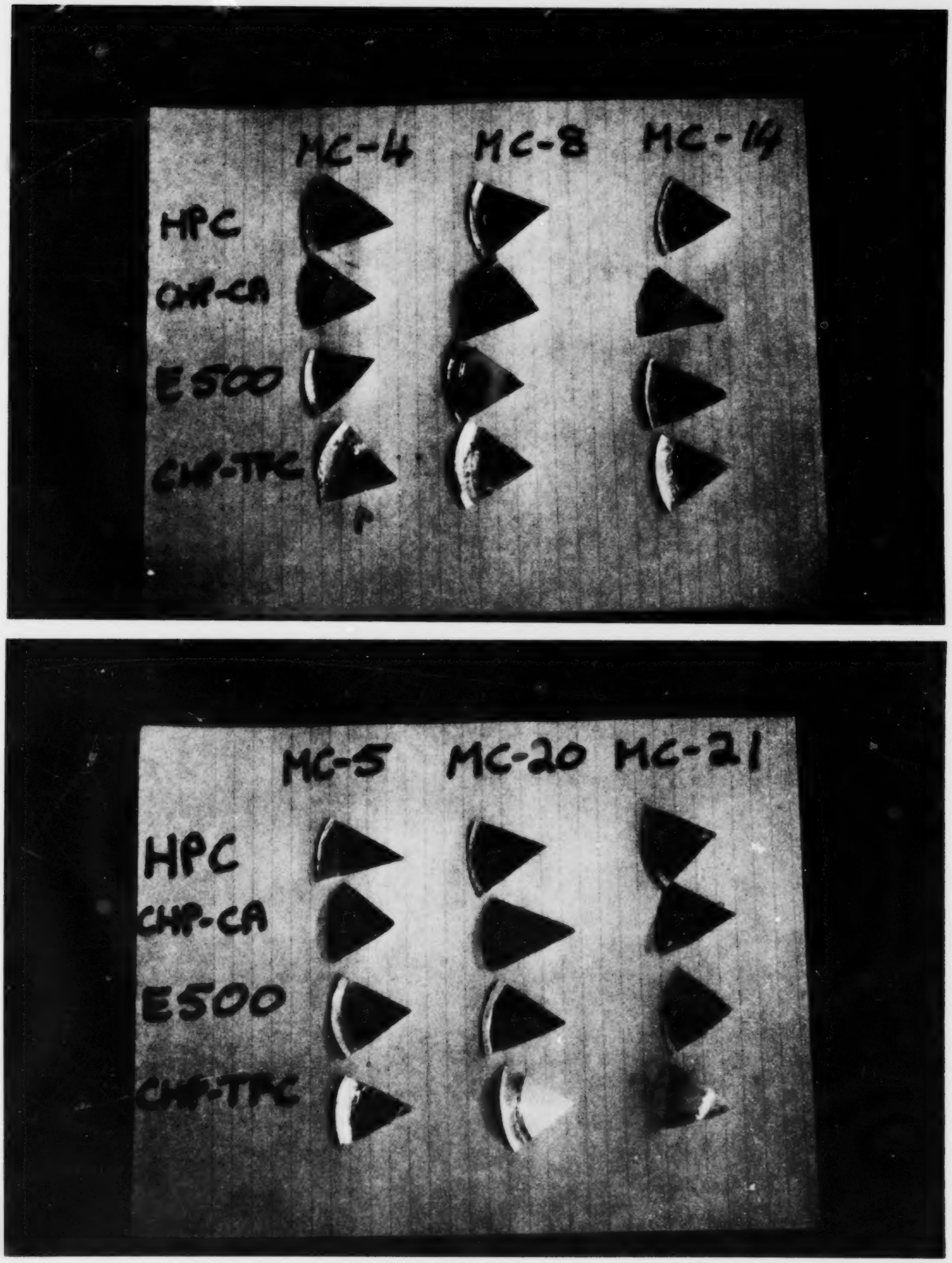
The rejections for all membranes were very similar except for membrane G10 which again produced a slightly higher quality permeate. Rejections of conductivity were 59% - 69%, of turbidity and suspended solids were virtually 100%, of TOC were 46% - 83%, of TDS were 77% - 92%, and silica were 34% - 48%. Rejections did not change significantly as the temperature increased.

3.3 Static Membrane Cleaning Tests

Figure 3-4 shows the condition of the coupons of membranes from the 85°C operation of the NRC cells after static cleaning with six cleaners. Membranes HPC and the polysulphone E500 were the most difficult membranes to clean. The CHP-CA membrane cleaned slightly better but was damaged by the enzyme cleaner (MC-8) and by the solvent cleaners. Oil on the surface of the membrane CHP-TFC was removed by all of the cleaners much more easily than from the surface of any of

FIGURE 3-4

Membranes From 85 Degree C Test After Static Cleaning


MC-4
MC-8
MC-14
HPC
CHP-CA
E500
CHP-TFC
MC-5
MC-20
MC-21
HPC
CHP-CA
E500
CHP-TFC

the other membranes. The MC-4 and MC-8 cleaners containing anionic surfactant and enzymes respectively cleaned most of the fouling oil from the surface of the TFC membrane. Cleaner MC-20 and 21 with surfactant and solvent were able to completely remove all visible oil fouling the TFC membrane.

Figure 3-5 shows the conditions of coupons of membranes from the 65°C operation of the NRC cells after static cleaning with cleaners MC-30, 31, 32, 40, 41, and 42. At the end of the 65°C run these membranes were not as badly fouled as the membranes from the 85°C run. As in the previous cleaning test, the E500 membrane was the most resistant to cleaning and the CHP-CA showed signs of being damaged by the solvent cleaners. The HPC appeared to clean well with all cleaners although not quite as well with the pure solvents as with the solvents in combination with surfactant.

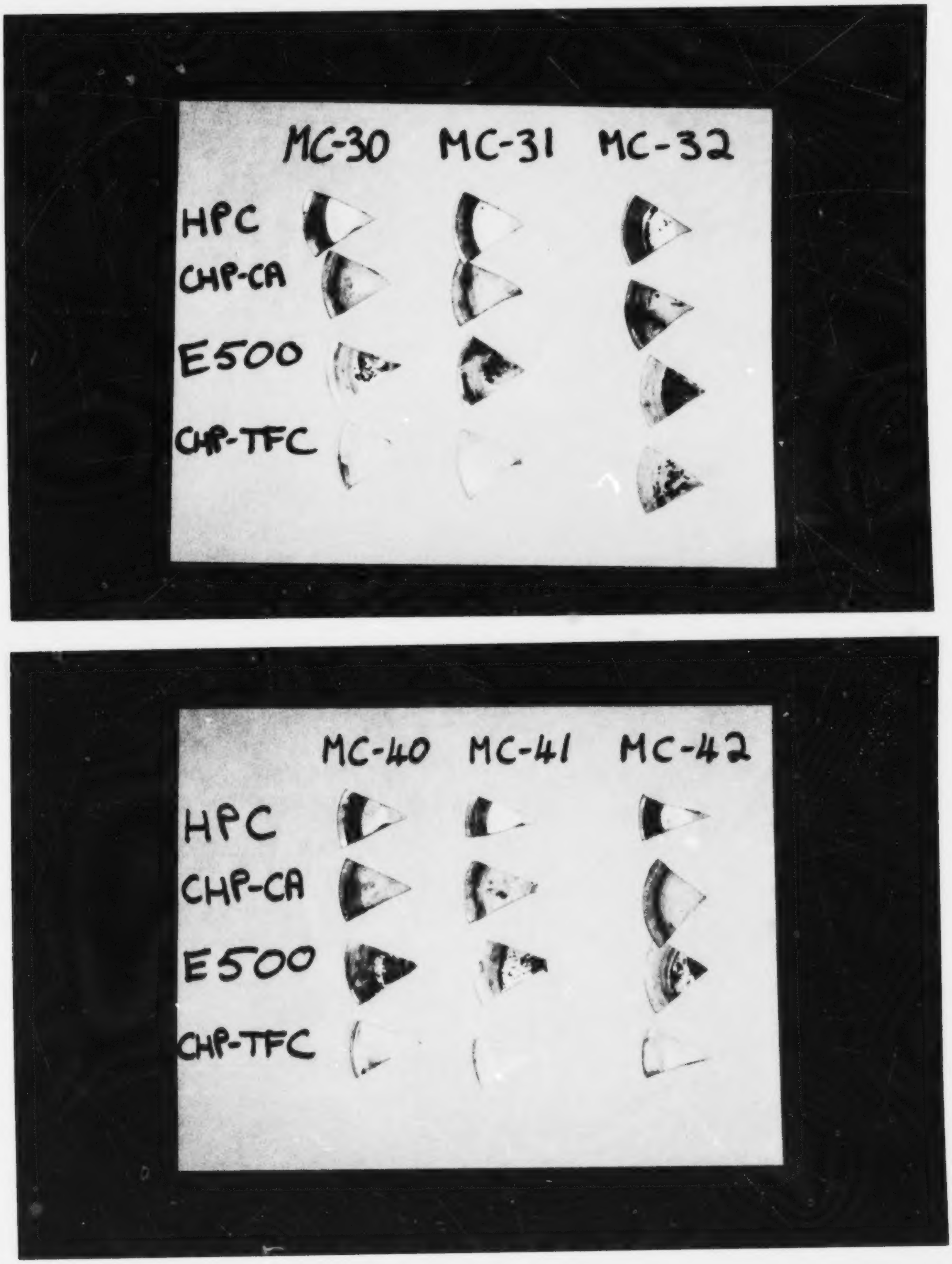
The TFC was again easier to clean than all of the other membranes although the pure naphtha cleaner was unable to remove all of the oil. The cleaners containing 10% and 50% naphtha and cyclohexane with surfactant all worked equally well at cleaning the TFC membrane.

The results of the tests demonstrate that different membranes respond in very different ways to cleaning. The E500 is a symetric polysulphone membrane and it is believed that contaminants pass into the membrane and foul the inside of pores in the membrane. This results in fouling which is deeply rooted in the membrane and is difficult to remove.

The TFC membrane is asymetric and has a thin tight surface with small openings which prevent fouling material from plugging the

FIGURE 3-5

Membranes From 65 Degree C Test After Static Cleaning


MC-30
MC-31
MC-32
HPC
CHP-CA
E500
CHP-TFC
MC-40
MC-41
MC-42
HPC
CHP-CA
E500
CHP-TFC

pores in the support membrane. The fouling which occurs is believed to be only on the surface and can therefore be removed much more easily than from the E500 (PS) or HPC membrane.

The conventional surfactant cleaners were partially effective in cleaning the membranes but the cleaners with both surfactant and solvent were much more effective. It is believed that the oil emulsion contains both polar and non-polar organics which may be responsible for fouling the membrane. The solvent activated cleaners are effective as they will act to dislodge both types of material fouling the membranes.

Based on the results of these tests, membrane cleaners MC-4 and solvent cleaners MC-20 and MC-40 were chosen for use in the tubular configuration cleaning tests. The MC-4 cleaner was included because of concerns that the solvent containing cleaners (MC-20 and MC-40) might damage the membranes.

3.4 Tubular Membrane Testing (Site "A" Wellhead)

3.4.1 Polyether Sulphone (PES) Membrane Test

During the first run with the polyethersulphone tubular membrane with a molecular weight cut off of 25 K, flux rates as shown in Figure 3-6 declined from an initial 12 m^3/m^2d to about 7 m^3/m^2d during concentration to a 90% volume reduction (concentration factor (CF) of 10). During the following 40 hours of operation some problems were encountered in maintaining the temperature of the process tank constant and the flux varied with changes in the temperature. At the end of 40 hours of operation, the flux rate had declined to about 5 m^3/m^2d and only a small flux recovery was observed after cleaning

FIGURE 3-6

Flux Rates for PES Tubular Membrane Test

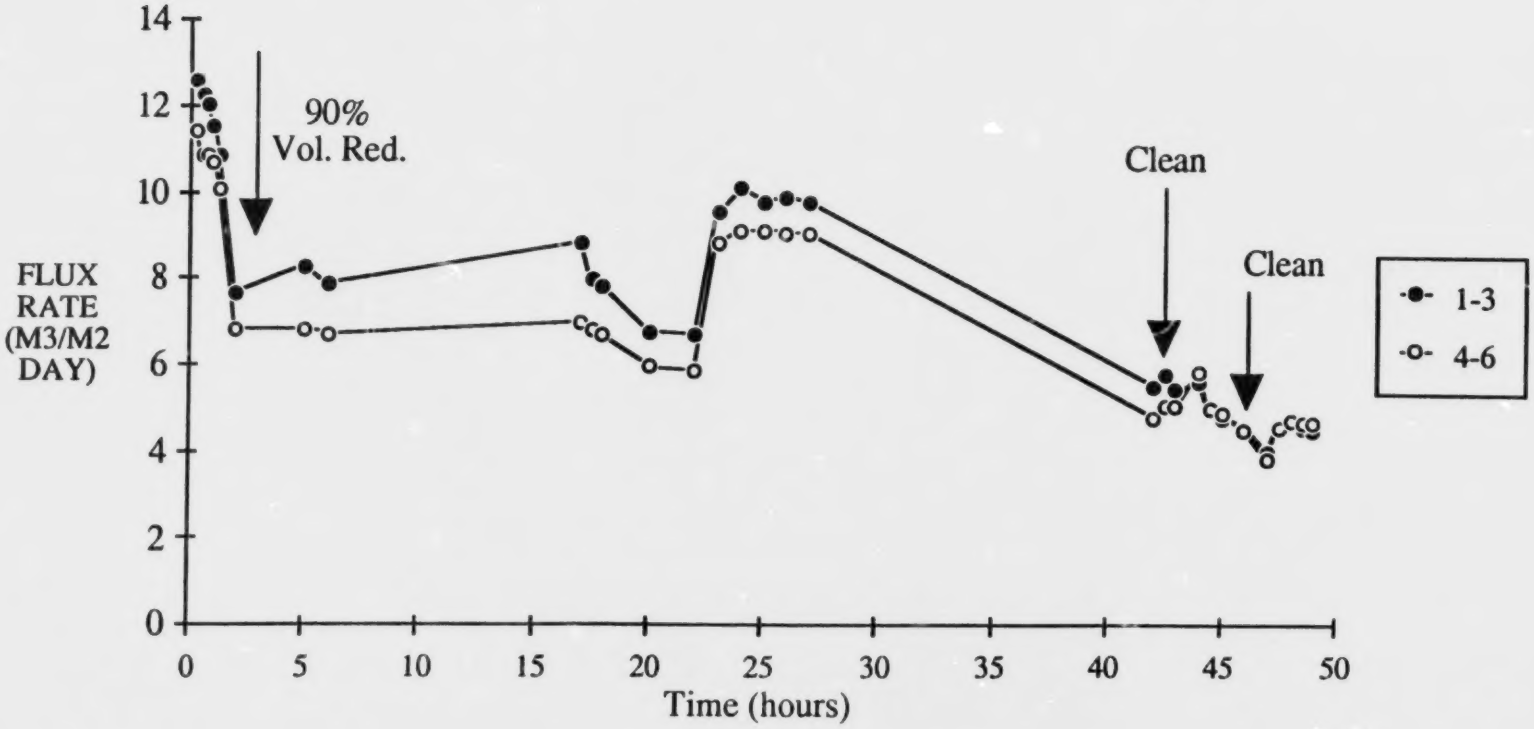


TABLE 3-9

PERMEATE QUALITY FOR PES MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = .75 hrs.			TIME = 1.25 hrs.		
		50% VOL. RED. CONC.	50% VOL. RED. PERM. TUBES 1-3	50% VOL. RED. PERM. TUBES 4-6	90% VOL. RED. CONC.	90% VOL. RED. PERM. TUBES 1-3	90% VOL. RED. PERM. TUBES 4-6
pH		7.51	7.64	7.17	7.65	7.54	7.76
COND.	umho	2.12	1.80	1.83	2.55	2.02	2.05
TURB.	NTU	1925.00	2.45	2.24	8850.00	2.45	2.38
TOC	mg/L	390	100	90	1400	170	190
TDS	mg/L	N/A	1325.0	1340.0	3242.5	1462.5	1492.5
TDO	mg/L	1037.50	330.00	245.00	1114.50	395.00	380.00
TSS	mg/L	212.5	0.0	0.0	714.0	0.0	0.0
TSO	mg/L	2750.0	0.0	0.0	8486.0	0.0	0.0
COLOUR	APHA	14500	160	220	41250	440	600
CALCIUM	mg/L	9.20	2.40	2.50	23.00	2.50	2.60
MAGNESIUM	mg/L	2.30	0.85	0.86	5.80	0.94	0.96
HARDNESS	mg/L	32.44	9.49	9.78	81.30	10.11	10.44
SILICA	mg/L	130	52	52	N/A	60	60

TABLE 3-10

PERCENT REJECTION FOR PES MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	TIME = 0.75 hr.		TIME = 1.25 hrs.	
	% REJ. 50% V.R. PERM. TUBES 1-3	% REJ. 50% V.R. PERM. TUBES 4-6	% REJ. 90% V.R. PERM. TUBES 1-3	% REJ. 90% V.R. PERM. TUBES 4-6
COND.	15%	14%	21%	20%
TURB.	100%	100%	100%	100%
TOC	74%	77%	88%	86%
TDS	N/A	N/A	55%	54%
TDO	68%	76%	65%	66%
TSS	100%	100%	100%	100%
TSO	100%	100%	100%	100%
COLOUR	99%	98%	99%	99%
CALCIUM	74%	73%	89%	89%
MAGNESIUM	63%	63%	84%	83%
HARDNESS	71%	70%	88%	87%
SILICA	60%	60%	N/A	N/A

% Rejections are based on Concentrate at Specified Volume Reduction

with MC-4 or MC-20 cleaners alone or with sponge balls.

Permeate quality and percent rejections based on concentrate at the specified volume reduction for this test are shown in Tables 3-9 and 3-10. Conductivity was rejected only to a slight degree and about 50% of the dissolved solids were rejected. Virtually all turbidity, and suspended solids and oil were rejected. Organic carbon rejections were near 75% at a 50% volume reduction (CF of 2) but increased to 97% at a 90% volume reduction (CF of 10). Dissolved oil rejections were near 70% and 99% of the colour was rejected throughout the test. The rejection of hardness was near 70% at a 50% volume reduction and increased to 85% as the concentrate became more concentrated. No sign of concentrated emulsion destabilization was observed during the test. After the test, the inside of the membrane tubes was inspected and no film of oil was observed fouling the membrane surface.

3.4.2 Polyvinyldifluoride (PVDF) Membrane Test

The second run with the PVDF membrane as shown in Figure 3-7 showed similar flux rates to the previous PES test. The flux rate dropped to 8 m^3/m^2d during concentration and showed a gradual decline to less than 5 m^3/m^2d during the following 90 hours of operation. Again cleaning resulted in very little recovery of flux.

Table 3-11 and 3-12 show the permeate quality results and rejections obtained during this test. Rejections were similar to those obtained during the PES membrane test. No significant changes in permeate quality were observed after cleaning with either the MC-4

FIGURE 3-7

Flux Rates for PVDF Tubular Membrane

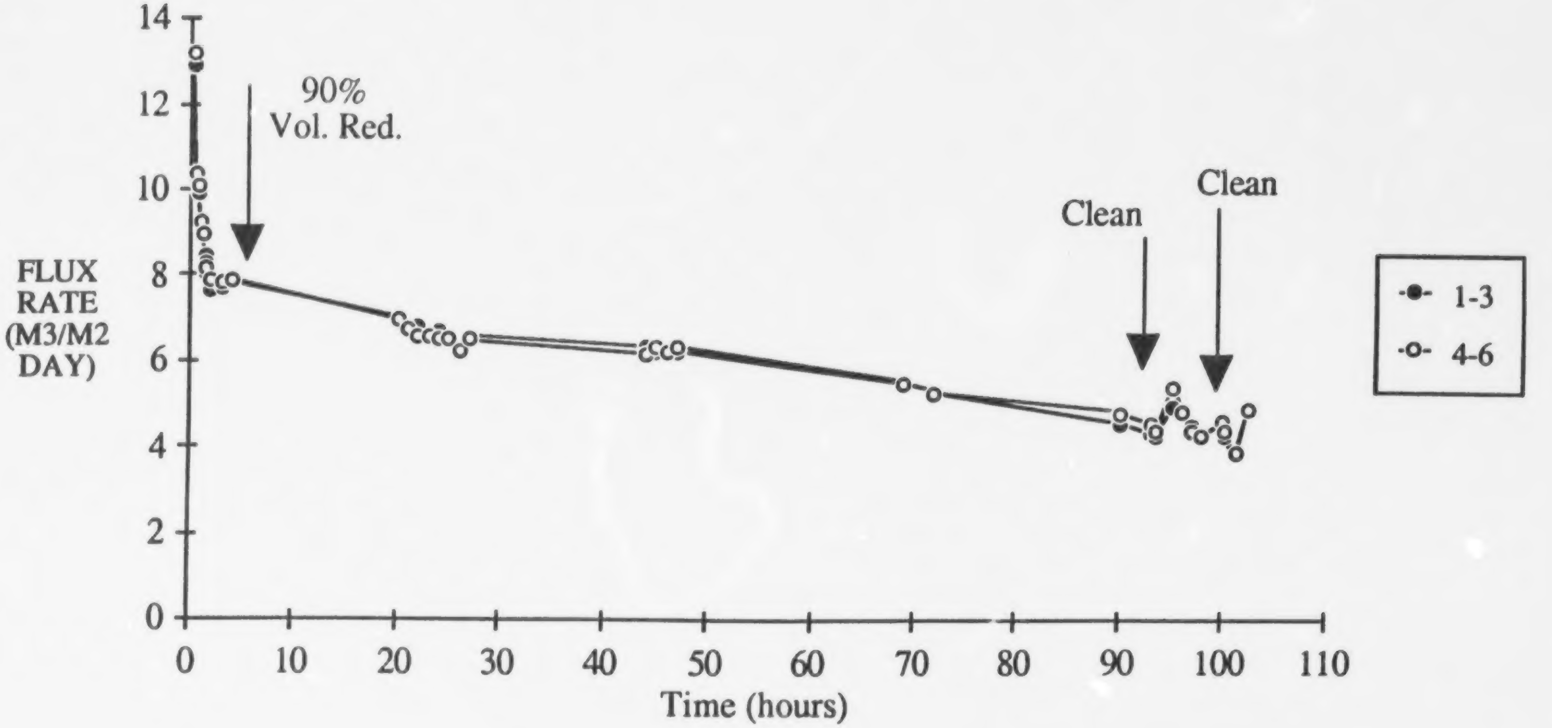


TABLE 3-11

PERMEATE QUALITY FOR PVDF MEMBRANE TEST
WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = .75 hr.			TIME = 1.5 hrs.			TIME=93.4 hrs.	TIME=95.25 hrs.		TIME = 100 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. TUBES 1-3	50% VOL. RED. PERM. TUBES 4-6	90% VOL. RED. CONC.	90% VOL. RED. PERM. TUBES 1-3	90% VOL. RED. PERM. TUBES 4-6	PRE-CLEAN PERM. 1-6	POST CLEAN #1 PERM. 1-3	POST CLEAN #1 PERM. 4-6	POST CLEAN #2 PERM. 1-3	POST CLEAN #2 PERM. 4-6
pH		7.4	7.9	7.6	7.6	7.3	7.4	8.3	7.6	8.2	7.6	7.7
COND.	umho	2.2	1.7	1.8	2.5	2.0	2.1	2.0	2.0	2.0	2.2	2.2
TURB.	NTU	1,585	2.8	2.9	6,450	3.4	4.3	1.0	2.2	1.3	1.3	1.6
TOC	mg/L	470	90	90	1000	180	180	250	260	180	210	240
TDS	mg/L	2,070	1,343	1,298	1,543	1,438	1,333	1,540	1,443	1,398	1,495	1,420
TDO	mg/L	603	245	283	1,115	373	445	255	398	430	498	413
TSS	mg/L	300.0	0.0	0.0	423.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TSO	mg/L	3,373	0.0	0.0	9,406	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLOUR	APHA	15,000	335	355	57,500	630	760	1,350	1,750	1,600	1,425	1,325
CALCIUM	mg/L	9.7	2.3	2.3	21.0	3.0	3.0	1.7	1.5	1.2	1.2	1.3
MAGNESIUM	mg/L	2.6	0.8	0.8	5.1	1.1	1.1	0.3	0.4	0.3	0.3	0.3
HARDNESS	mg/L	34.9	9.0	9.1	73.4	12.0	12.0	5.5	5.3	4.2	4.1	4.4
SILICA	mg/L	N/A	N/A	N/A	76	27	27	16	N/A	N/A	11	36

TABLE 3-12

PERCENT REJECTION FOR PVDF MEMBRANE TEST
WITH WELLHEAD EMULSION

PARAMETER	TIME = .75 hr.		TIME = 1.5 hrs.		TIME=93.5 hrs	TIME = 95.25 hrs		TIME = 100 hrs.	
	% REJ. 50% V.R. PERM. TUBES 1-3	% REJ. 50% V.R. PERM. TUBES 4-6	% REJ. 90% V.R. PERM. TUBES 1-3	% REJ. 90% V.R. PERM. TUBES 4-6	% REJ. PRE-CLEAN PERM. TUBES 1-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6
COND.	22%	20%	18%	18%	19%	18%	19%	14%	14%
TURB.	100%	100%	100%	100%	100%	100%	100%	100%	100%
TOC	81%	81%	82%	82%	75%	74%	82%	79%	76%
TDS	35%	37%	7%	14%	0%	6%	9%	3%	8%
TDO	59%	53%	67%	60%	77%	64%	61%	55%	63%
TSS	100%	100%	100%	100%	100%	100%	100%	100%	100%
TSO	100%	100%	100%	100%	100%	100%	100%	100%	100%
COLOUR	98%	98%	99%	99%	98%	97%	97%	98%	98%
CALCIUM	76%	76%	86%	86%	92%	93%	94%	94%	94%
MAGNESIUM	70%	69%	78%	78%	94%	93%	94%	95%	94%
HARDNESS	74%	74%	84%	84%	92%	93%	94%	94%	94%
SILICA	N/A	N/A	64%	64%	79%	N/A	N/A	86%	53%

% Rejections are based on Concentrate at Specified Volume Reduction

or MC-40 cleaner. No sign of concentrated emulsion destabilization was observed during the test.

3.4.3 CHP-CA Membrane Test

The third test with the CHP-CA membrane showed similar flux rates to the PES membranes and a very gradual flux decline during 70 hours of operation at a 90% volume reduction (CF of 10). Figure 3-8 shows the flux data for this test.

Permeate quality and percent rejections are shown in Table 3-13 and 3-14. Again, rejections of most components were similar to those obtained for both the PES and PVDF membranes previously described. No significant decreases in rejections were observed after cleaning. Again no sign of emulsion destabilization was observed during the run.

3.4.4 CHP-TFC Membrane Test

The fourth test with the CHP-TFC membrane as shown in Figure 3-9 had flux rates initially slightly lower than in the previous tests (5 m^3/m^2d) but there was no decline in flux rates at all during concentration or during 200 hours of operation. Cleaning of the membrane resulted in a slight increase in flux rate.

Permeate quality and rejections are presented in Tables 3-15 and 3-16. Rejections of conductivity and TOC are slightly better than with the PES and CHP-CA membrane. Rejections of other components are very similar. No sign of concentrated emulsion destabilization was observed.

FIGURE 3-8

Flux Rates for CHP-CA Tubular Membrane

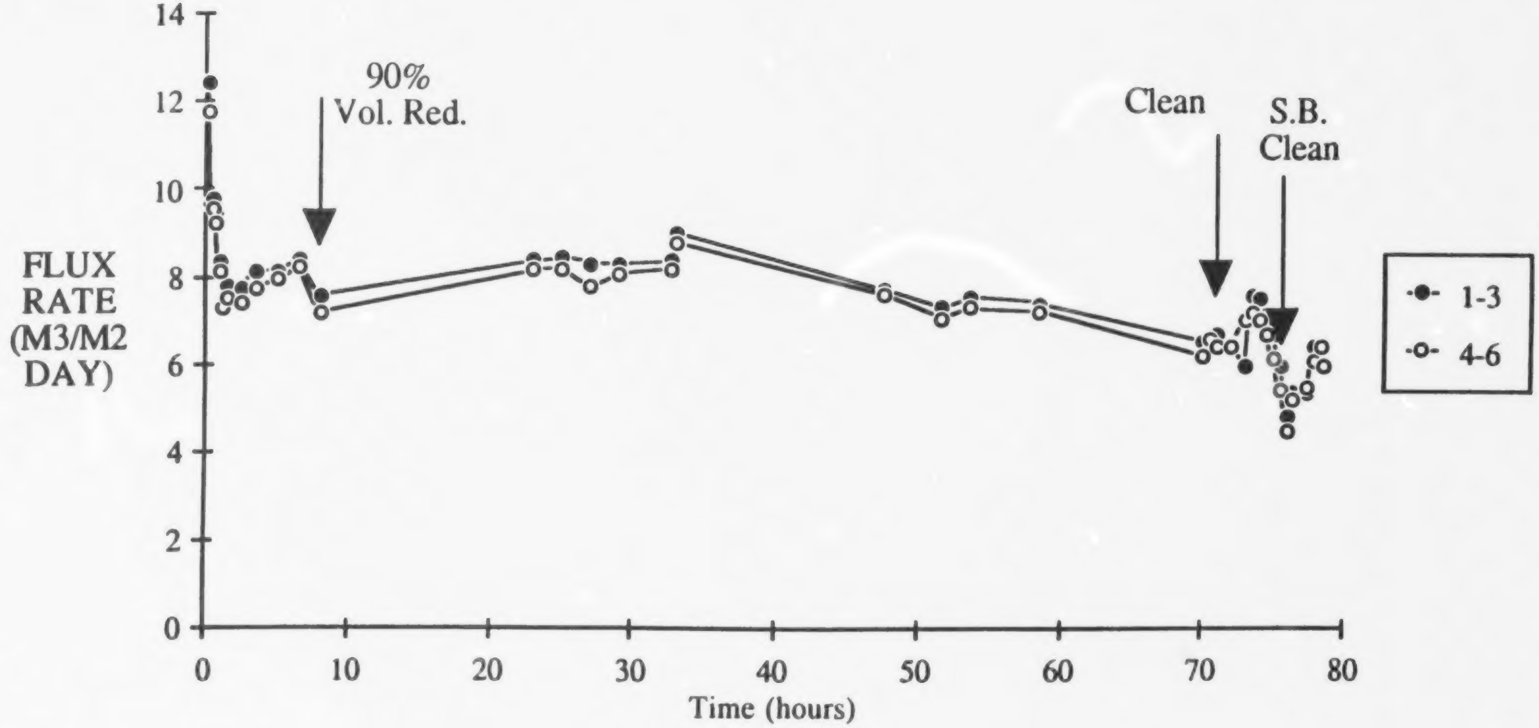


TABLE 3-13

PERMEATE QUALITY FOR CHP-CA MEMBRANE TEST
WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = .75 hrs.			TIME = 2.5 hrs.			TIME = 73 hrs.		TIME = 77.25 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. TUBES 1-3	50% VOL. RED. PERM. TUBES 4-6	90% VOL. RED. CONC.	90% VOL. RED. PERM. TUBES 1-3	90% VOL. RED. PERM. TUBES 4-6	POST CLEAN #1 PERM. 1-3	POST CLEAN #1 PERM. 4-6	POST CLEAN #2 PERM. 1-3	POST CLEAN #2 PERM. 4-6
pH		7.83	8.02	7.97	8.02	8.21	8.30	8.62	8.58	8.61	8.60
COND.	umho	2.30	1.76	1.82	2.62	2.27	2.33	2.71	2.75	2.53	2.64
TURB.	NTU	885.00	4.90	1.28	6650.00	2.15	1.25	1.36	0.99	0.70	0.50
TOC	mg/L	470	100	140	1200	200	230	280	310	290	320
TDS	mg/L	1787.5	1137.5	1185.0	2310.5	1540.0	1532.5	1777.5	1962.5	1830.0	1910.0
TDO	mg/L	1,000.0	290.0	215.0	1,671.5	382.5	437.5	507.5	585.0	580.0	602.5
TSS	mg/L	337.5	0.0	0.0	734.0	0.0	0.0	0.0	0.0	0.0	0.0
TSO	mg/L	3,137.5	0.0	0.0	10,539.5	0.0	0.0	0.0	0.0	0.0	0.0
COLOUR	APHA	12,500	480	540	70,000	1,650	1,150	2,650	2,800	2,250	2,900
CALCIUM	mg/L	12.00	5.30	8.90	31.00	3.30	5.20	2.00	2.50	2.00	2.50
MAGNESIUM	mg/L	2.60	0.60	0.76	7.10	0.95	1.10	0.27	0.34	0.27	0.33
HARDNESS	mg/L	40.67	15.70	25.35	106.63	12.15	17.51	6.11	7.64	6.11	7.60
SILICA	mg/L	40.00	19.00	19.00	110.00	21.00	21.00	N/A	N/A	14.00	21.00

TABLE 3-14

PERCENT REJECTION FOR CHP-CA MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	TIME = .75 hrs.		TIME = 2.5 hrs.		TIME = 73 hrs.		TIME = 77.25 hrs.	
	% REJ. 50% V.R. PERM. TUBES 1-3	% REJ. 50% V.R. PERM. TUBES 4-6	% REJ. 90% V.R. PERM. TUBES 1-3	% REJ. 90% V.R. PERM. TUBES 4-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6	% REJ. POST#2 CL. PERM. TUBES 1-3	% REJ. POST#2 CL. PERM. TUBES 4-6
COND.	24%	21%	13%	11%	0%	0%	3%	0%
TURB.	99%	100%	100%	100%	100%	100%	100%	100%
TOC	79%	70%	83%	81%	77%	74%	76%	73%
TDS	36%	34%	33%	34%	23%	15%	21%	17%
TDO	71%	79%	77%	74%	70%	65%	65%	64%
TSS	100%	100%	100%	100%	100%	100%	100%	100%
TSO	100%	100%	100%	100%	100%	100%	100%	100%
COLOUR	96%	96%	98%	98%	96%	96%	97%	96%
CALCIUM	56%	26%	89%	83%	94%	92%	94%	92%
MAGNESIUM	77%	71%	87%	85%	96%	95%	96%	95%
HARDNESS	61%	38%	89%	84%	94%	93%	94%	93%
SILICA	53%	53%	81%	81%	N/A	N/A	87%	81%

FIGURE 3-9

Flux Rates for CHP-TFC Tubular Membrane

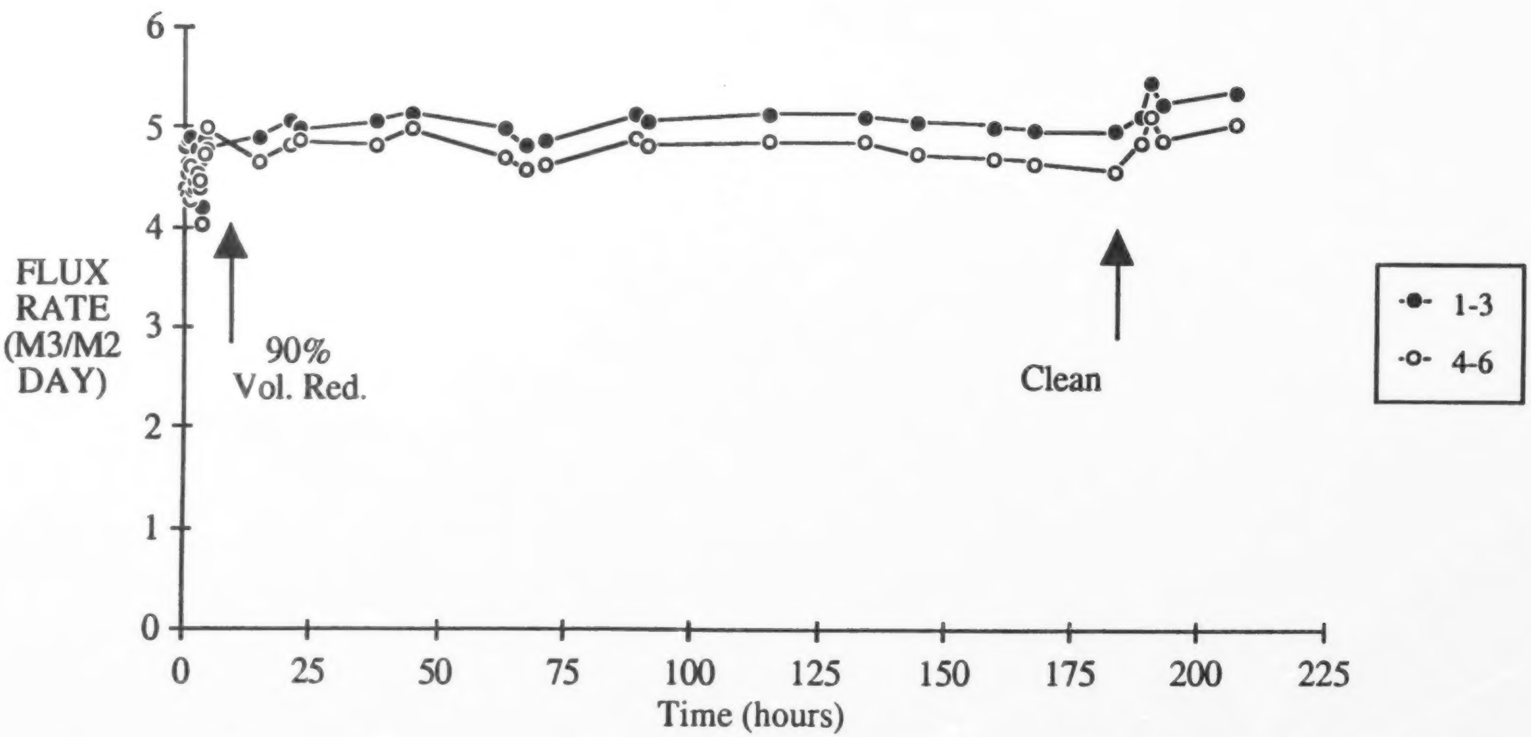


TABLE 3-15

PERMEATE QUALITY FOR CHP-TFC MEMBRANE TEST
WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = 2.0 hrs.			TIME = 3.75 hrs.			TIME=188 hrs.	TIME = 190 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. TUBES 1-3	50% VOL. RED. PERM. TUBES 4-6	90% VOL. RED. CONC.	90% VOL. RED. PERM. TUBES 1-3	90% VOL. RED. PERM. TUBES 4-6	COMP. PERM PRIOR TO CLEANING	POST CLEAN #1 PERM. 1-3	POST CLEAN #1 PERM. 4-6
pH		7.6	7.2	7.4	7.6	7.7	7.6	8.5	7.9	7.7
COND.	umho	2.4	1.6	1.7	3.3	2.1	2.1	2.4	2.3	2.4
TURB.	NTU	1,050	3.7	3.2	1,050	2.9	3.2	1.2	1.4	1.7
TOC	mg/L	320	46	39	1,200	75	66	110	110	120
TDS	mg/L	1,813	960	1,013	3,038	1,213	1,225	1,600	1,575	1,650
TDO	mg/L	725	380	490	1,025	685	735	157	590	433
TSS	mg/L	338	0	0	734	0	0	0	0	0
TSO	mg/L	3,138	0	0	10,540	0	0	0	0	0
COLOUR	APHA	14,000	73	85	40,000	165	195	240	225	250
CALCIUM	mg/L	9.0	1.4	1.4	22.0	1.9	2.1	4.0	2.3	2.4
MAGNESIUM	mg/L	2.6	0.6	0.6	6.1	0.8	0.9	0.8	0.7	0.7
HARDNESS	mg/L	33.2	5.8	5.8	80.0	8.0	8.8	13.2	8.7	9.0

TABLE 3-16

PERCENT REJECTION FOR CHP-TFC MEMBRANE TEST
WITH WELLHEAD EMULSION

PARAMETER	TIME = 2.0 hrs.		TIME = 3.75 hrs.		TIME = 190 hrs.	
	% REJ. 50% V.R. PERM. TUBES 1-3	% REJ. 50% V.R. PERM. TUBES 4-6	% REJ. 90% V.R. PERM. TUBES 1-3	% REJ. 90% V.R. PERM. TUBES 4-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6
COND.	30%	29%	37%	36%	28%	30%
TURB.	100%	100%	100%	100%	100%	100%
TOC	86%	88%	94%	95%	91%	91%
TDS	47%	44%	60%	60%	47%	48%
TDO	48%	32%	33%	28%	85%	42%
TSS	100%	100%	100%	100%	100%	100%
TSO	100%	100%	100%	100%	100%	100%
COLOUR	99%	99%	100%	100%	99%	99%
CALCIUM	84%	84%	91%	90%	82%	90%
MAGNESIUM	78%	78%	87%	86%	87%	88%
HARDNESS	83%	82%	90%	89%	83%	89%

% Rejections are based on Concentrate at Specified Volume Reduction

3.4.5 HPC Membrane Test

The fifth test with a large pore HPC membrane resulted in a very stable flux rate as shown in Figure 3-10 of just less than 8 m^3/m^2d for a period of over 160 hours. Cleaning of the membrane resulted in a slight increase in flux rates and no sign of emulsion destabilization was observed.

Permeate quality and rejections are shown in Tables 3-17 and 3-18. Rejections were similar to those obtained during the previous runs. Some decrease in permeate quality with respect to TOC, dissolved oil, and colour were observed after cleaning with both the MC-4 and MC-40 cleaners.

3.4.6 Polyolefin (PO) Membrane Test

The sixth test with the polyolefin membrane resulted in a very stable flux rate as shown in Figure 3-11 of about 5 m^3/m^2d over 170 hours of testing.

Permeate quality results are presented in Tables 3-19 and 3-20. The permeate throughout the test was considerably lower than during tests with other membranes. This is reflected in the low rejection of colour (70 - 93%) as compared with the other membranes (99%). No sign of emulsion destabilization was observed during the test.

3.4.7 Selection Of Optimal Membrane Type

Table 3-21 shows the permeate quality at a 90% volume reduction for each of the 6 membranes tested. Permeate quality is similar for PES, PVDF, CHP-CA, and HPC, slightly better for CHP-TFC

FIGURE 3-10

Flux Rates for HPC Tubular Membrane Test

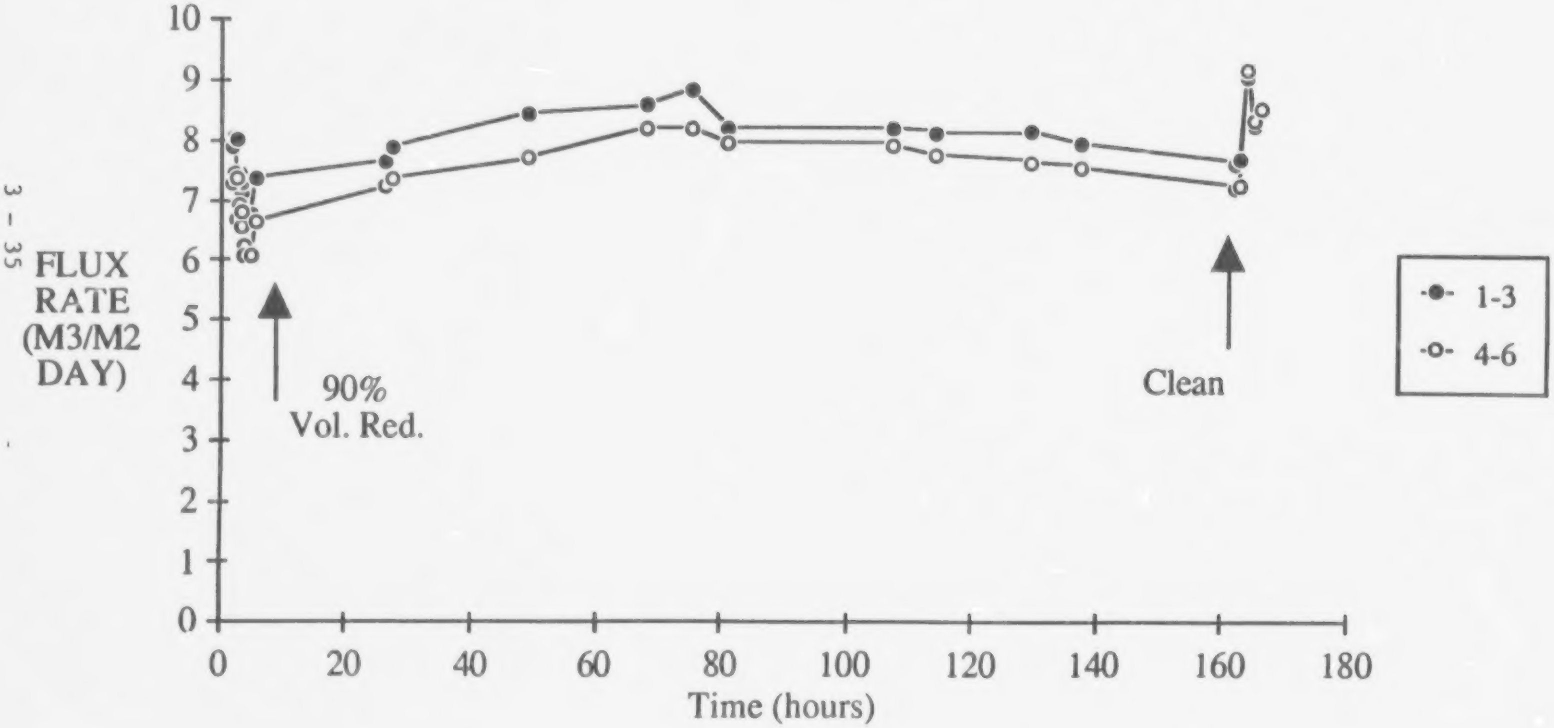


TABLE 3-17

PERMEATE QUALITY FOR HPC MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = 2.5 hrs.			TIME = 3.62 hrs.			TIME=162 hrs.	TIME = 164 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. TUBES 1-3	50% VOL. RED. PERM. TUBES 4-6	90% VOL. RED. CONC.	90% VOL. RED. PERM. TUBES 1-3	90% VOL. RED. PERM. TUBES 4-6	COMP. PERM PRIOR TO CLEANING	POST CLEAN #1 PERM. 1-3	POST CLEAN #1 PERM. 4-6
pH		7.66	7.98	7.8	7.76	8.01	7.78	8.59	8.47	8.5
COND.	umho	2.17	1.87	1.86	2.66	2.21	2.20	2.46	2.29	2.28
TURB.	NTU	1,720	1.15	1.20	6,000	0.51	1.20	0.72	0.78	0.60
TOC	mg/L	370	98	N/A	1,100	220	190	300	370	320
TDS	mg/L	3,608	1,190	1,275	N/A	1,500	1,505	N/A	N/A	N/A
TDO	mg/L	476	100	210	1,250	365	400	690	920	810
TSS	mg/L	63.0	0.0	0.0	87.5	0.0	0.0	0.0	0.0	0.0
TSO	mg/L	1,680.0	0.0	0.0	6,000.0	0.0	0.0	0.0	0.0	0.0
COLOUR	APHA	16,500	540	510	45,000	1,700	1,300	2,800	4,000	4,600
CALCIUM	mg/L	8.00	2.10	2.10	18.00	3.10	3.00	1.70	2.20	2.00
MAGNESIUM	mg/L	2.20	0.78	0.78	5.10	1.10	1.10	0.35	0.44	0.41
HARDNESS	mg/L	29.03	8.45	8.45	65.94	12.27	12.02	5.69	7.30	6.68
SILICA	mg/L	32.00	11.00	11.00	56.00	18.00	18.00	18.00	9.60	22.00

TABLE 3-18

PERCENT REJECTION FOR HPC MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	TIME = 2.5 hrs.		TIME = 3.62 hrs.		TIME = 164 hrs.	
	% REJ. 50% V.R. PERM. TUBES 1-3	% REJ. 50% V.R. PERM. TUBES 4-6	% REJ. 90% V.R. PERM. TUBES 1-3	% REJ. 90% V.R. PERM. TUBES 4-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6
COND.	14%	14%	17%	17%	14%	14%
TURB.	100%	100%	100%	100%	100%	100%
TOC	74%	N/A	80%	83%	66%	71%
TDS	67%	65%	N/A	N/A	N/A	N/A
TDO	79%	56%	71%	68%	26%	35%
TSS	100%	100%	100%	100%	100%	100%
TSO	100%	100%	100%	100%	100%	100%
COLOUR	97%	97%	96%	97%	91%	90%
CALCIUM	74%	74%	83%	83%	88%	89%
MAGNESIUM	65%	65%	78%	78%	91%	92%
HARDNESS	71%	71%	81%	82%	89%	90%
SILICA	66%	66%	68%	68%	83%	61%

FIGURE 3-11

Flux Rates for PO Tubular Membrane Test

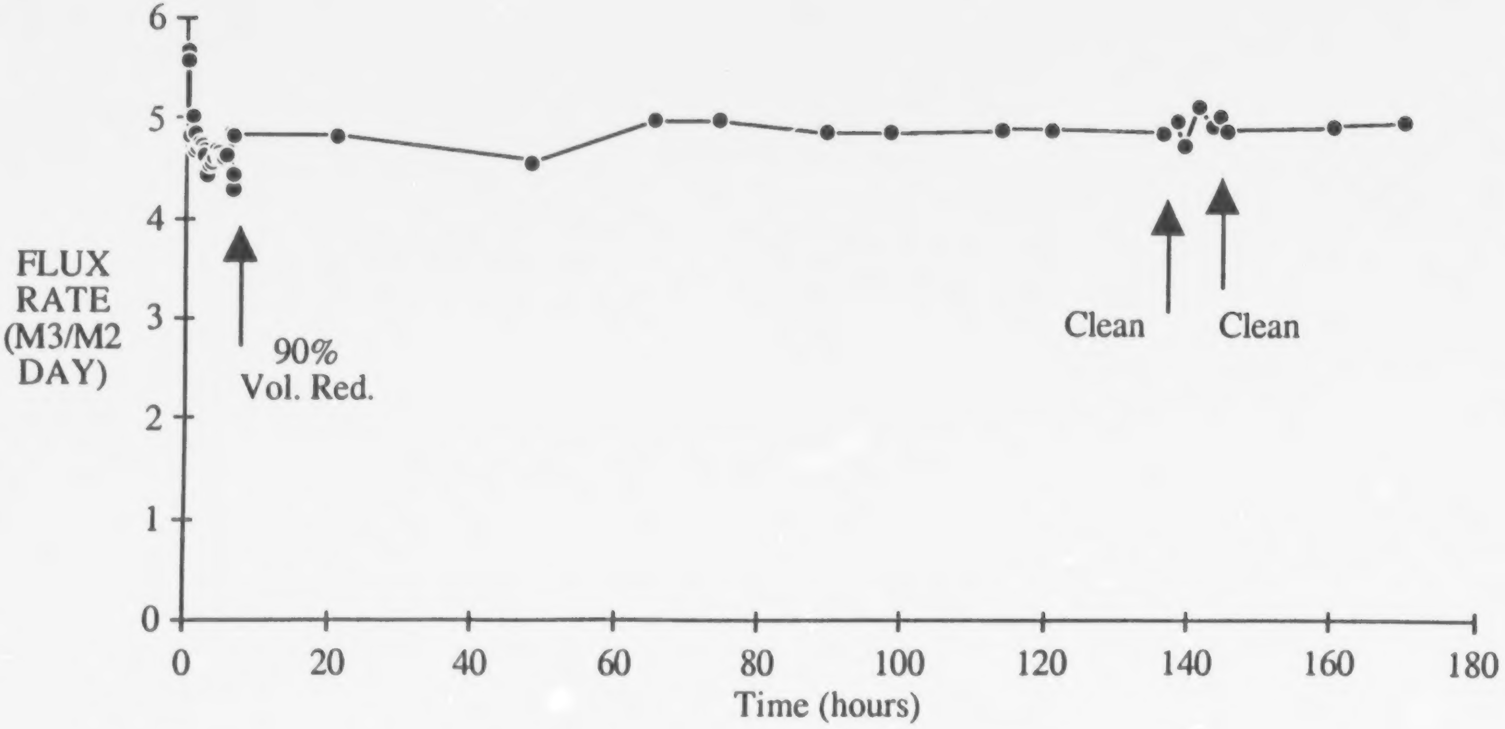


TABLE 3-19

PERMEATE QUALITY FOR PO MEMBRANE TEST WITH WELLHEAD EMULSION

PARAMETER	UNITS	TIME = 3.5 hrs.		TIME = 6.5 hrs.		TIME=138 hrs	TIME=139 hrs	TIME=144 hrs.
		50% VOL. RED. CONC.	50% VOL. RED. PERM.	90% VOL. RED. CONC.	90% VOL. RED. PERM.	PERM. PRIOR TO CLEANING	POST CLEAN #1	POST CLEAN #2
pH		7.90	8.02	8.03	8.07	8.47	8.35	8.04
COND.	umho	2.04	1.93	2.19	2.04	2.14	2.15	2.15
TURB.	NTU	1,450.00	0.95	6,000.00	0.21	0.16	0.15	0.16
COLOUR	APHA	15,000	1,050	50,000	2,700	3,900	4,000	4,500
Ca	mg/L	6.6	2.7	18	3.1	0.83	0.72	0.85
Mg	mg/L	1.70	0.92	3.80	1.00	0.19	0.19	0.25
HARDNESS	mg/L	23.48	10.53	60.59	11.86	2.85	2.58	3.15
DIS. SILICA	mg/L	N/A	73	N/A	78	87	39	49

TABLE 3-20

PERCENT REJECTION PO MEMBRANE TEST WITH WELLHEAD EMULSION

	TIME=3.5 hrs.	TIME=6.5 hrs.	TIME=138 hrs	TIME=139 hrs.	TIME=144 hrs.
PARAMETER	% REJ. 50% V.R. PERM.	% REJ. 90% V.R. PERM.	% REJ. PRIOR TO CLEANING	% REJ. POST#1 CL. PERM.	% REJ. POST#2 CL. PERM.
COND.	6%	7%	2%	2%	2%
TURB.	100%	76%	100%	100%	100%
COLOUR	93%	70%	92%	92%	91%
Ca	59%	63%	95%	96%	95%
Mg	46%	55%	95%	95%	93%
HARDNESS	55%	61%	95%	96%	95%
DIS. SILICA	N/A	N/A	N/A	N/A	N/A

TABLE 3-21

COMPARISION OF PERMEATE QUALITY FROM DIFFERENT MEMBRANES AT 90% VOL. RED.

	PES	PVDF	CHP-CA	HPC	CHP-TFC	PO
CONCENTRATE CONDUCTIVITY	2.6	2.5	2.6	2.7	3.3	2.2
PERMEATE CONDUCTIVITY	2.0	2.0	2.3	2.2	2.1	2.0
CONCENTRATE TURBIDITY	8,850	6,450	6,650	6,000	1,050	6,000
PERMEATE TURBIDITY	2.4	3.9	1.7	0.9	3.0	0.2
CONCENTRATE TOC	1,400	1,000	1,200	1,100	1,200	N/A
PERMEATE TOC	180	180	215	205	70.5	N/A
CONCENTRATE TDS	3,242	1,542	2,310	N/A	3,037	N/A
PERMEATE TDS	1,477	1,384	1,536	N/A	1,218	N/A
CONCENTRATE TDO	1,114	1,114	1,671	1,250	1,025	N/A
PERMEATE TDO	387	408	409	382	710	N/A
CONCENTRATE COLOUR	41,250	57,500	70,000	45,000	40,000	50,000
PERMEATE COLOUR	520	695	1,400	1,500	187	2,700
CONCENTRATE Ca	23	21	31	18	22	18
PERMEATE Ca	2.6	3.0	4.3	3.1	2.0	3.1
CONCENTRATE Mg.	5.8	5.1	7.1	5.1	6.1	3.8
PERMEATE Mg.	1.0	1.1	1.0	1.1	0.8	1.0
CONCENTRATE HARDNESS	81	73	107	66	80	61
PERMEATE HARDNESS	10	12	15	12	8	12
CONCENTRATE DIS. SILICA	N/A	76	110	56	N/A	N/A
PERMEATE DIS. SILICA	60	27	21	18	N/A	N/A

All units are mg/L except conductivity (umho), turbidity (NTU) and colour (APHA).

and considerably worse for PO.

The CHP-TFC, HPC, and PO membranes tested had high and very stable flux rates for extended periods of time. Cleaning of the membranes was not required even after 6 days of operation at a 90% volume reduction because no decline in flux was observed. The CHP-TFC membrane was selected as the most suitable membrane for this application as a result of its high and stable flux and high quality permeate.

3.5 Tubular and Spiral Testing (Site "A" HTS)

Figure 3-12 shows the flux rate results for the tubular CHP-TFC membrane test conducted with the HTS sample. The initial flux rate was slightly greater than 3.5 m^3/m^2d and remained at that level during concentration and operation at a 90% volume reduction. After further concentration to a 95% volume reduction or concentration factor of 20, the flux dropped to near 3.0 m^3/m^2d and remained at this level for 24 hours. Cleaning with MC-4 and MC-40 both resulted in the flux rate increasing to 3.5 m^3/m^2d. Tables 3-22 and 3-23 show the permeate quality results for this experiment. Rejections of contaminants are similar to those observed during previous tubular tests and no decrease in permeate quality was observed after cleaning.

Figure 3-13 shows the flux rate results for the spiral TFC test conducted using HTS water. The flux rate decreased from about 2 to 1 m^3/m^2d during the initial concentration to a volume reduction of 30% (CF 1.43). The flux rate was relatively stable during further concentration to a CF of 2.5 and 24 hours of operation of at this level. After cleaning with MC-40 the flux rate increased to almost 3

FIGURE 3-12

Flux Rates for CHP-TFC Tubular Membrane Test With HTS Water

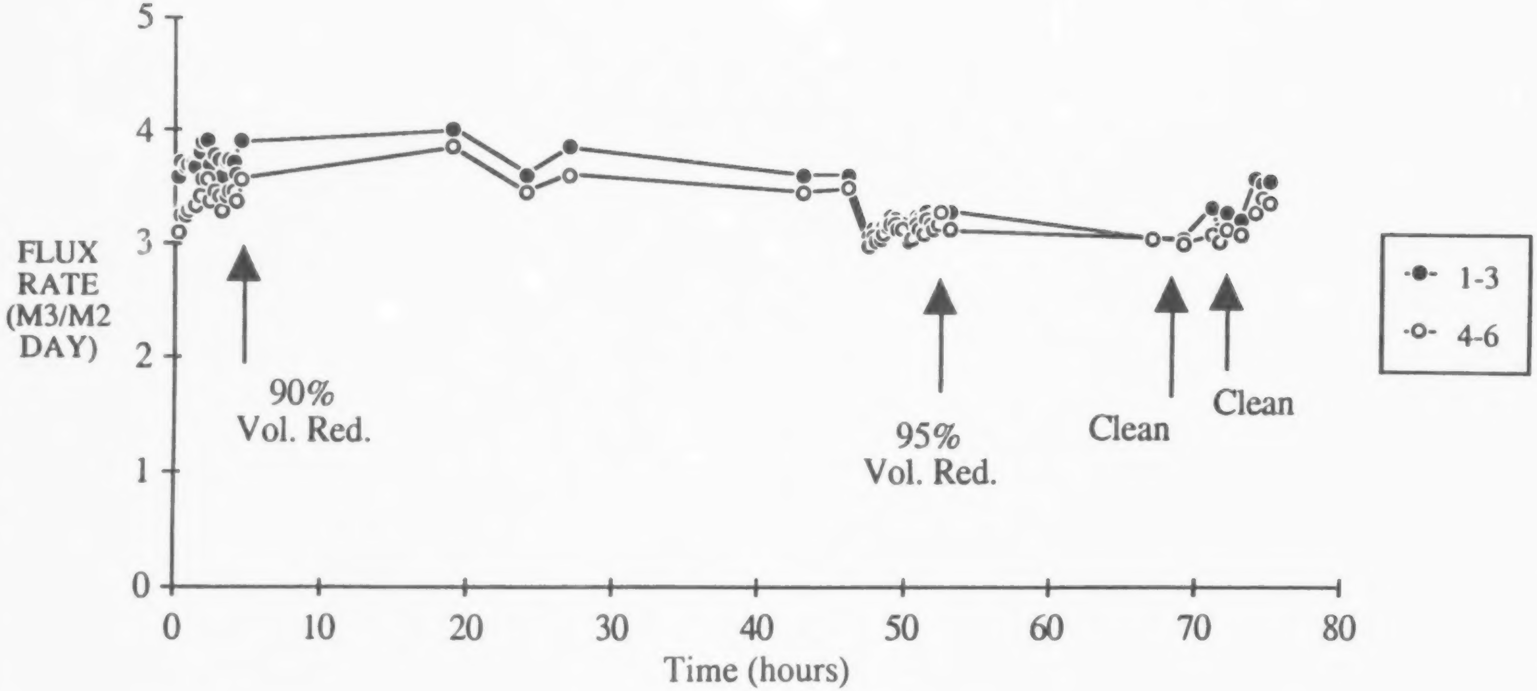


TABLE 3-22

PERMEATE QUALITY FOR CHP-TFC MEMBRANE TEST WITH HTS WATER

PARAMETER	UNITS	TIME = 2.5 hr.		TIME = 4.25 hrs.		TIME = 52.33 hrs		TIME=69 hrs.	TIME=71 hrs.		TIME = 74 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. COMP.	90% VOL. RED. CONC.	90% VOL. RED. PERM. COMP.	95% VOL. RED. CONC.	95% VOL. RED. PERM. TUBES 4-6	PRE-CLEAN PERM.	POST CLEAN #1 PERM. 1-3	POST CLEAN #1 PERM. 4-6	POST CLEAN #2 PERM. 1-3	POST CLEAN #2 PERM. 4-6
pH		7.72	7.13	8.02	7.83	7.89	7.57	8.76	8.69	8.67	8.72	8.72
COND.	umho	2.32	1.71	3.14	2.26	3.68	2.50	2.62	2.64	2.62	2.68	2.71
TURB.	NTU	167.50	3.50	545.00	2.85	15.45	4.20	3.00	1.20	2.10	1.55	1.20
TOC	mg/L	420	45	1194	93	2131	139	157	159	144	161	156
TDS	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TDO	mg/L	1212.0	275.5	N/A	141.0	3114.0	554.0	651.0	350.0	305.0	240.0	385.0
TSS	mg/L	27.0	0.0	40.5	0.0	127.0	0.0	0.0	0.0	0.0	0.0	0.0
TSO	mg/L	222.5	0.0	605.0	0.0	998.5	0.0	0.0	0.0	0.0	0.0	0.0
COLOUR	APHA	14000	150	37500	450	62500	500	395	335	335	380	375
CALCIUM	mg/L	12.00	2.90	29.00	4.10	55.00	2.90	1.00	1.10	1.10	1.10	1.10
MAGNESIUM	mg/L	3.00	0.90	7.10	1.30	14.00	0.81	0.19	0.22	0.23	0.22	0.22
HARDNESS	mg/L	42.31	10.95	101.64	15.59	194.96	10.58	3.28	3.65	3.69	3.65	3.65

TABLE 3-23

PERCENT REJECTION FOR CHP-TFC MEMBRANE TEST
WITH HTS WATER

PARAMETER	TIME=2.5 hr.	TIME=4.25 hrs.	TIME =52.3 hrs	TIME=71 hrs.		TIME = 74 hrs.	
	% REJ. 30% V.R. PERM.	% REJ. 90% V.R. PERM.	% REJ. 95% V.R. PERM.	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6	% REJ. POST#1 CL. PERM. TUBES 1-3	% REJ. POST#1 CL. PERM. TUBES 4-6
COND.	26%	28%	32%	29%	28%	27%	26%
TURB.	98%	99%	73%	81%	92%	90%	92%
TOC	89%	92%	94%	93%	93%	92%	93%
TDO	77%	N/A	82%	79%	89%	92%	88%
TSS	100%	100%	100%	100%	100%	100%	100%
TSO	100%	100%	100%	100%	100%	100%	100%
COLOUR	99%	99%	99%	99%	99%	99%	99%
CALCIUM	76%	86%	95%	98%	98%	98%	98%
MAGNESIUM	70%	82%	94%	99%	98%	98%	98%
HARDNESS	74%	85%	95%	98%	98%	98%	98%

FIGURE 3-13

Flux Rates for CHP-TFC Spiral Membrane with HTS Water

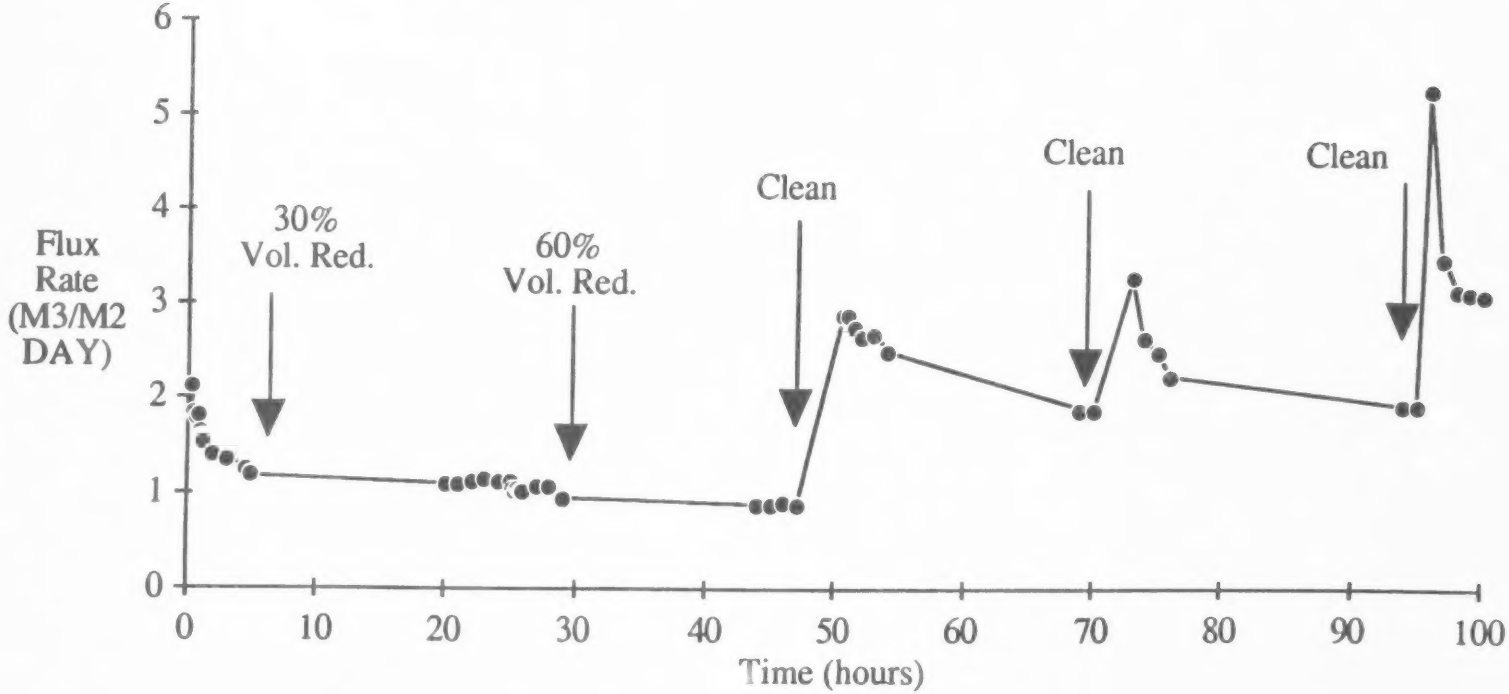


TABLE 3-24

PERMEATE QUALITY FOR CHP-TFC SPIRAL MEMBRANE TEST WITH HTS WATER

PARAMETER	UNITS	TIME = 1.3 hr.		TIME = 25.9 hrs.		TIME = 50.5 hrs		TIME=70 hrs.	TIME=96 hrs.	
		30% VOL. RED. CONC.	30% VOL. RED. PERM. COMP.	60% VOL. RED. CONC.	60% VOL. RED. PERM. COMP.	POST CLEAN #1 FEED	POST CLEAN #1 PERM.	PRE-CLEAN #2 PERM.	POST CLEAN #2 FEED	POST CLEAN #2 PERM.
pH		7.04	6.73	7.47	7.19	7.75	8.06	8.12	8.00	8.25
COND.	umho	2.16	1.47	2.54	1.71	2.57	1.86	1.68	2.51	1.85
TURB.	NTU	160.00	2.50	192.00	1.85	165.00	1.60	1.43	120.50	1.91
COLOUR	APHA	7,500	125	13,500	150	11,000	225	175	11,000	380

TABLE 3-25

PERCENT REJECTION FOR CHP-TFC SPIRAL MEMBRANE WITH HTS WATER

PARAMETER	TIME=1.3 hr.	TIME=25.9 hrs	TIME=50.5 hrs	TIME=70 hrs.	TIME=96 hrs.
	% REJ. 30% V.R. PERM.	% REJ. 60% V.R. PERM.	% REJ. POST CLEAN #1	% REJ. PRE. CLEAN #2	% REJ. POST CLEAN #2
COND.	32%	33%	28%	35%	26%
TURB.	98%	99%	99%	99%	98%
COLOUR	98%	99%	98%	98%	97%

FIGURE 3-14

Flux Rates for CHP-TFC Spiral Membrane with HTS Permeate Feed

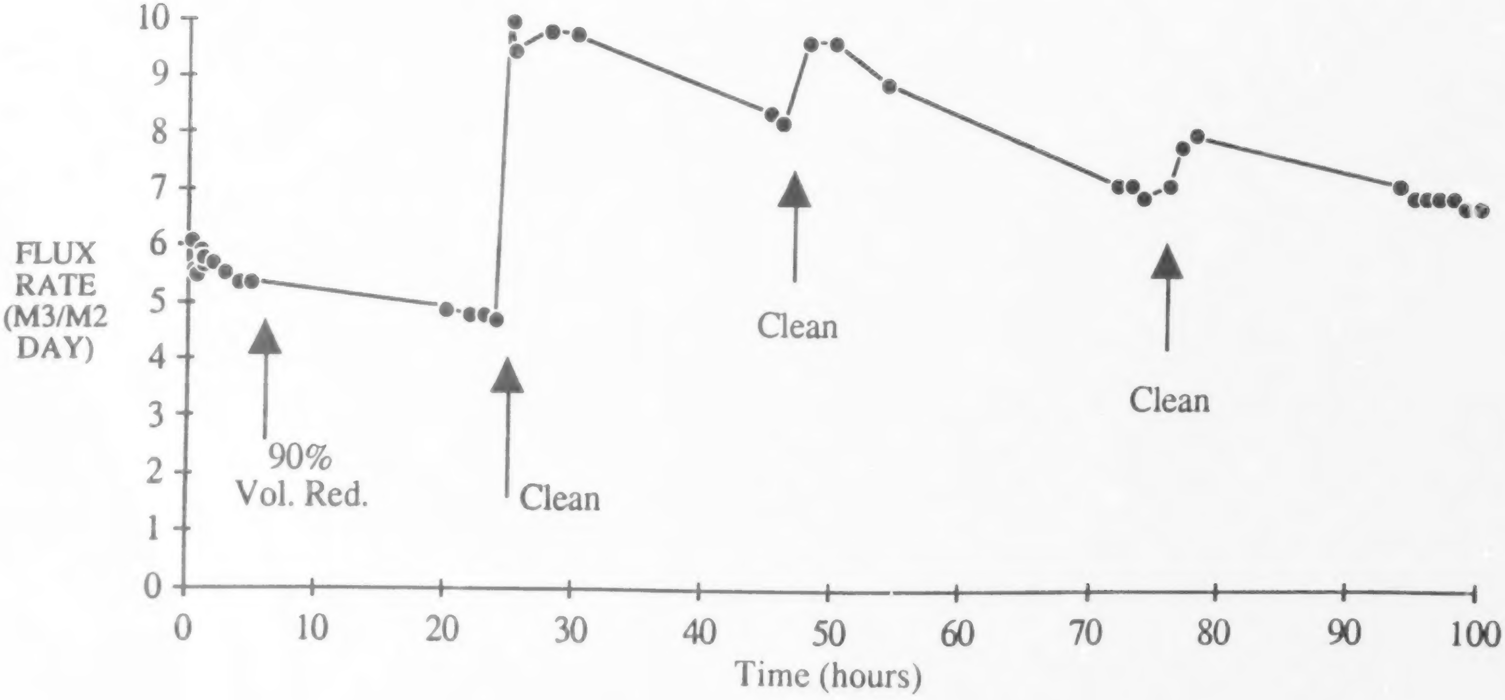


TABLE 3-26

PERMEATE QUALITY FOR CHP-TFC SPIRAL MEMBRANE TEST WITH PERMEATE FROM HTS CHP-TFC SPIRAL TEST

PARAMETER	UNITS	TIME = 1.17 hr.		TIME = 1.33 hrs.	
		50% VOL. RED. CONC.	50% VOL. RED. PERM. COMP.	90% VOL. RED. CONC.	90% VOL. RED. PERM. COMP.
pH		7.12	7.05	7.37	6.98
COND.	umho	1.83	1.68	2.04	1.87
TURB.	NTU	3.70	1.32	4.00	1.58
COLOUR	APHA	150	100	265	150

TABLE 3-27

PERCENT REJECTION FOR CHP-TFC SPIRAL MEMBRANE TEST WITH PERMEATE FROM HTS CHP-TFC SPIRAL TEST

PARAMETER	TIME=1.17 hr.	TIME=1.33 hrs.
	% REJ. 50% V.R. PERM.	% REJ. 90% V.R. PERM.
COND.	8%	8%
TURB.	64%	61%
COLOUR	33%	43%

m^3/m^2d then decreased to about 2 m^3/m^2d during 20 hours of operation. At this point in time, a second cleaning was conducted and the flux rate jumped to above 3.2 m^3/m^2d then declined to about 2.0 m^3/m^2d over 22 hours of operation. After a third cleaning with MC-40, the flux rate increased to above 5 m^3/m^2d then dropped quickly to about 3 m^3/m^2d.

Figure 3-14 shows the flux rate data for the tight TFC spiral test conducted using permeate from the tubular test as feed. The flux rates during this test were considerably higher than were obtained during the previous spiral test. During concentration to a 90% volume reduction and 24 hours of operation at this level the flux decreased from about 6 m^3/m^2d to slightly below 5 m^3/m^2d. Cleaning with cleaner MC-40 resulted in a flux rate increase to 10 m^3/m^2d which decreased to about 8 m^3/m^2d over 20 hours of operation. A second cleaning at this point in time with cleaner MC-4 was able to return the flux to 10 m^3/m^2d. A third cleaning with MC-40 was only partially effective in restoring the flux rate.

Flux rate increases were observed during previous tubular membrane tests after cleaning with MC-4 and MC-40 cleaners but the increase in this test was much more significant than had been observed earlier. It is believed that the cleaner is flushing contaminant material from the casting process from the polysulphone support membrane allowing for higher fluxes to be obtained.

3.6 Long Term Testing with Different Emulsions

Table 3-28 shows the characteristics of all seven of the produced water samples tested in this set of experiment. The results

TABLE 3 - 28

RAW FEED CHARACTERISTICS FOR TESTING WITH DIFFERENT SAMPLES

PARAMETER	SITE A HTS	SITE B Wellhead	SITE C Skim Tank	SITE D Skim Tank	SITE E Skim Tank	SITE F FWKO	SITE G FWKO&HTS
pH	7.7	8.0	6.5	6.4	8.1	6.1	8.9
TDS (mg/L)	1,528	2,205	3,760	35,800	6,250	13,050	3,010
TDO (mg/L)	390	277	122	3,295	220	935	550
TSS(mg/L)	25	52	272	576	320	326	0
TSO (mg/L)	73	1,738	46	276	116	211	0
FOC (mg/L)	240	103	130	37	150	88	750
TURBIDITY (NTU)	56	6,700	250	210	100	105	240
COLOUR (ALPHA)	NA	NA	1,500	750.00	1,250	500	2,500
CONDUCTIVITY (umho)	2.0	3.0	5.7	44.7	9.0	17.8	2.9
HARDNESS (mg/L)	30	79	180	2,652	219	1,244	86
EXTRACTABLE OILS (mg/L)	NA	NA	40	230	100	66	NA
OIL (mg/L)	NA	NA	44	220	84	78	NA
SURFACTANTS (mg/L)	NA	NA	14	12	17	8	NA
ANIONS (mg/L)							
Bromide	<0.3	3.30	6.30	< 0.8	10.00	43.00	1.70
Chloride	570	850	1,900	17,000	3,830	5,100	560
Fluoride	4.90	2.80	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Nitrate (as N)	<0.08	0.09	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nitrite (as N)	<0.08	<0.08	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Phosphate (as P)	0.84	<0.3	< 0.8	< 0.8	< 0.8	< 0.8	< 0.8
Sulfate	68.00	360.00	11.00	< 1.0	71.00	26.00	51.00
CATIONS (mg/L)							
Aluminum	0.52	0.33	< 0.03	< 0.03	< 0.03	< 0.03	0.47
Barium	0.05	0.19	0.31	8.50	0.55	9.00	0.20
Beryllium	<0.01	<0.01	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003
Boron	NA	NA	40.00	15.00	51.00	31.00	24.00
Cadmium	0.01	0.09	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Calcium	8.80	20.00	59.00	600.00	74.00	300.00	26.00
Chromium	0.02	<0.01	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Cobalt	<0.02	<0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Copper	0.01	0.03	< 0.006	< 0.006	0.02	< 0.006	0.02
Iron	0.36	0.57	45.00	3.50	40.00	8.20	0.15
Lead	0.10	0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
Magnesium	2.00	7.15	7.90	280.00	8.30	120.00	5.00
Manganese	0.04	0.06	0.37	0.32	0.64	0.82	0.01
Molybdenum	0.06	0.03	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Nickel	<0.02	0.09	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009
Phosphorous	NA	NA	0.69	5.30	1.30	1.40	< 0.10
Potassium	13.50	64.00	79.00	84.00	87.00	120.00	34.00
Silicon as Si	104.00	84.00	36.00	17.00	68.00	36.00	93.00
Silver	<0.02	<0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium	430	640	1,290	11,200	2,170	4,190	840
Strontium	0.40	1.26	1.10	20.00	1.30	20.00	0.98
Thallium	NA	NA	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Titanium	NA	NA	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Vanadium	0.04	0.16	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Zinc	0.12	0.05	0.06	0.05	< 0.005	0.15	< 0.005
Zirconium	NA	NA	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

TDS - TOTAL DISSOLVED SOLIDS
TDO - TOTAL DISSOLVED OILS
TSS - TOTAL SUSPENDED SOLIDS
TSO - TOTAL SUSPENDED OILS
FOC - FILTERED ORGANIC CARBON

show considerable variation in produced water characteristics from different sites.

3.6.1 Test #1, Site A, HTS

The sample used for this test was obtained from the high temperature separator in the treatment process at site "A" and is from the same sample described in Section 3.4 and 3.5.

Figure 3-15 shows the flux rates obtained during this test and Table 3-29 and 3-30 show the permeate quality generated. The initial flux rate was slightly above 3.0 m^3/m^2/day and decreased to about 2.6 m^3/m^2/day during concentration to a 90% volume reduction (CF = 10). After this point, the permeate was recycled back to process tank and no further concentration was carried out. The flux rate decreased to approximately 1.5 m^3/m^2/day over the following 40 hours of operation after which time the system was cleaned. After cleaning the flux rate increased to above 2.5 m^3/m^2/day but decreased slightly to about 2.2 m^3/m^2/day over the following 240 hours of operation. The system was again cleaned and the flux increased slightly then returned back down to a level of about 2.3 m^3/m^2/day.

A previous test conducted using the CHP-TFC membranes and the same sample of produced water from the effluent of the HTS unit at Site "A" demonstrated that a stable flux of 3.5 m^3/m^2/day could be obtained with this sample. The somewhat lower flux obtained during this second test is believed due to a slight variation in the membranes used in the two tests. The permeate quality results show very similar rejections of components as in the first test with the HTS water from this site.

FIGURE 3 - 15

FLUX RATE VS TIME
for Test #1, Site A, HTS

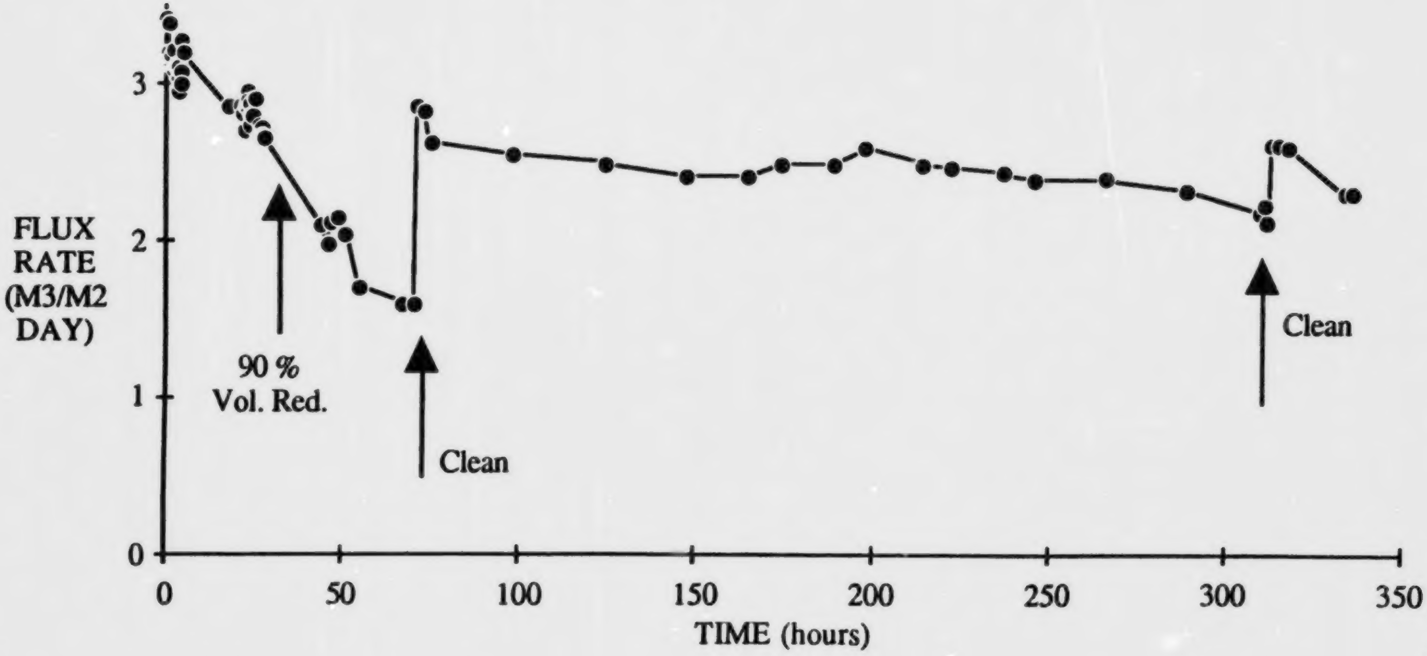


TABLE 3 - 29

PERMEATE QUALITY FOR TEST #1 SITE A, HTS

DATE: JUNE 12, 1986

MEMBRANE: CHP - TFC

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 30 hr.	TIME = 30 hr.		TIME = 68 hr.		TIME = 71 hr.	TIME = 308 hr.		TIME = 310 hr.
		RAW FEED	COMPOSITE PERMEATE	90 % Vol. Red. CONC.	90 % Vol. Red. PERMEATE	PRE-CLEAN CONC.	PRE-CLEAN PREMEATE	POST-CLEAN PERMEATE	PRE-CLEAN CONC.	PRE-CLEAN PREMEATE	POST-CLEAN PERMEATE
pH		7.17	7.59	7.42	7.46	7.96	8.00	8.15	8.22	8.26	8.01
COND.	umho	1.95	1.69	2.66	2.06	3.15	2.19	2.25	3.16	2.34	2.35
TURB.	NTU	130	1.0	840	2.7	1,400	1.4	1.6	1,400	1.3	2.6
TOC	mg/L	391	51	1,230	83	2,120	96	107	2,300	168	241
COLOUR	APHA	2,500	100	30,000	220	30,000	210	240	30,000	350	415
CALCIUM	mg/L	8.4	3.6	28.0	4.2	38.0	1.7	1.8	41.0	1.4	1.6
MAGNESIUM	mg/L	2.0	1.0	5.5	1.2	7.4	0.5	0.6	8.1	0.3	0.4
HARDNESS	mg/L	29.2	13.0	92.6	15.4	125.3	6.3	6.8	135.7	4.7	5.8
SILICA	mg/L	88	84	110	88	190	86	90	510	130	130

TABLE 3 - 30

PERCENT REJECTION FOR TEST #1 SITE A, HTS

DATE: JUNE 12, 1986

MEMBRANE: CHP - TFC

	TIME = 0 - 30 hr.	TIME = 30 hr.	TIME = 68 hr.	TIME = 71 hr.	TIME = 308 hr.	TIME = 310 hr.
PARAMETER	COMPOSITE	90 % V.R.	PRE-CLEAN	POST-CLEAN	PRE-CLEAN	POST-CLEAN
COND.	13%	23%	30%	29%	26%	26%
TURB.	99%	100%	100%	100%	100%	100%
TOC	87%	93%	95%	95%	93%	90%
COLOUR	96%	99%	99%	99%	99%	99%
CALCIUM	57%	85%	96%	95%	97%	96%
MAGNESIUM	51%	78%	93%	92%	96%	95%
HARDNESS	55%	83%	95%	95%	97%	96%
SILICA	5%	20%	55%	53%	75%	75%

3.6.2 Test #2 Site B, Wellhead

The sample used for this test was obtained from the wellhead at a different field location than the previous samples tested. The sample contained a high concentration of emulsified oil and considerably more free oil than had been present in the wellhead sample obtained from Site A.

Figure 3-16 shows the flux rates obtained during this test and Table 3-31 and 3-32 show the permeate quality generated. Initially, the flux rate was approximately 4.0 m^3/m^2/day. This flux rate decreased during concentration to a 65% volume reduction (CF = 2.8) to approximately 1.0 m^3/m^2/day and as a result of the low flux rate obtained no concentration beyond the 65% volume reduction level was attempted.

The flux rate remained stable at the level of 1.0 m^3/m^2/day for the following 115 hours after which time the system was cleaned. After cleaning the flux increased to 4.5 m^3/m^2/day but decreased quickly to 1.0 m^3/m^2/day. The flux rate then decreased very gradually over the following 180 hours of operation to approximately 0.5 m^3/m^2/day. At the end of the run, the membranes were visibly fouled with a layer of oily material. The characteristics of the flux curve are typical of a system in which severe fouling of the membrane has occured.

The permeate quality generated during this test was similar to that obtained in previous tests.

FIGURE 3 - 16

FLUX RATE VS TIME
for Test #2, Site B, Wellhead

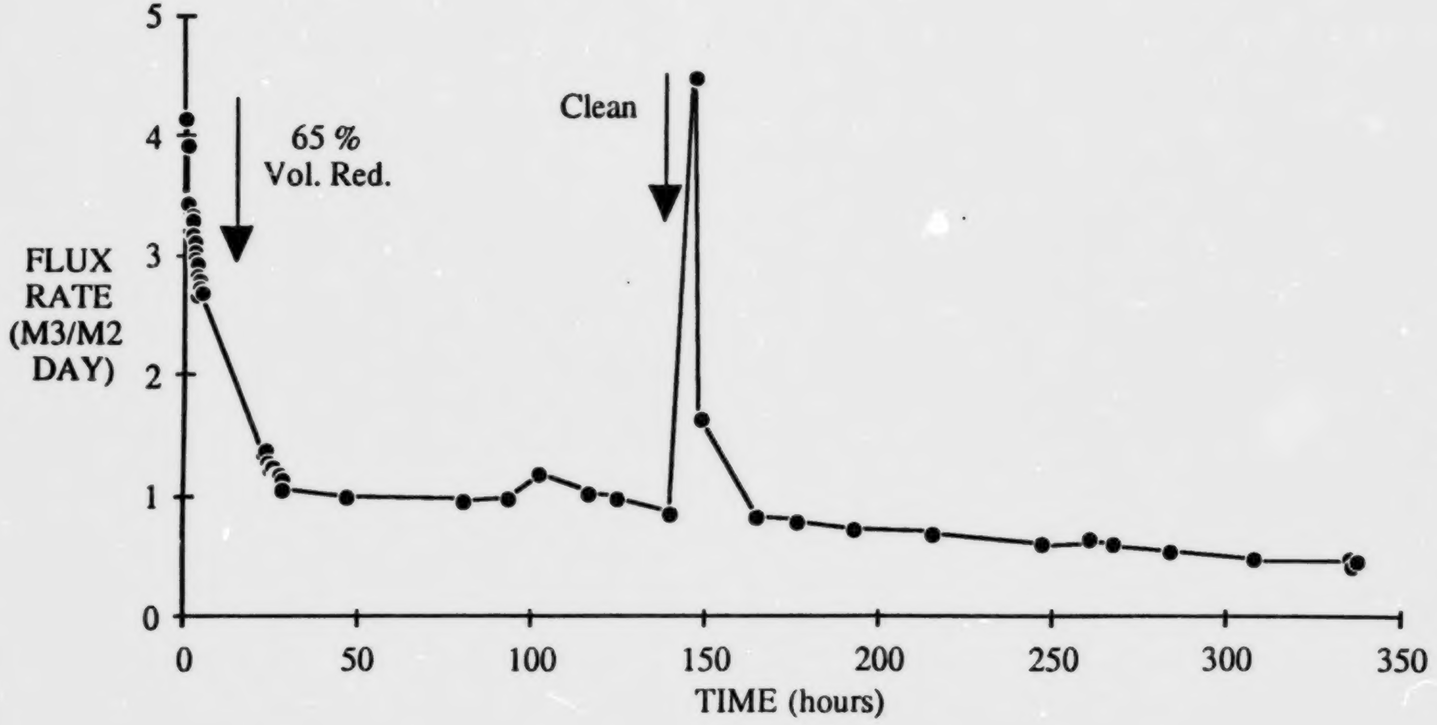


TABLE 3 - 31

PERMEATE QUALITY FOR TEST #2 SITE B, Wellhead

DATE: JUNE 12, 1986

MEMBRANE: CHP - TFC

PARAMETER	UNITS	TIME = 0 hr	TIME = 0 - 20 hr.	TIME = 20 hr.	TIME = 145 hr.	TIME = 147 hr.	TIME = 298 hr.	TIME = 300 hr.
		RAW FEED	COMPOSITE PERMEATE	65 % Vol. Red. CONC.	PRE-CLEAN PERMEATE	POST-CLEAN PERMEATE	PRE-CLEAN PERMEATE	POST-CLEAN PERMEATE
pH		7.96	7.30	7.30	7.85	7.77	7.25	7.51
COND.	umho	3.0	2.8	4.4	3.4	3.7	4.3	4.2
TURB.	NTU	6,700	1.4	240	16	12	4.2	5.2
TOC	mg/L	N/A	28	150	42	69	72	84
COLOUR	APHA	N/A	175	2,250	290	475	450	500
CALCIUM	mg/L	20	18	35	18	22	29	33
MAGNESIUM	mg/L	7	4	17	7	9	15	15
HARDNESS	mg/L	79	61	157	72	91	134	144
SILICA	mg/L	84	120	115	140	143	130	125

TABLE 3 - 32

PERCENT REJECTION FOR TEST #2 SITE B, Wellhead

DATE: JUNE 12, 1986 MEMBRANE: CHP - TFC

PARAMETER	TIME = 0 - 20 hr. COMPOSITE PERMEATE	TIME = 145 hr. PRE-CLEAN PERMEATE	TIME = 147 hr. POST-CLEAN PERMEATE	TIME = 298 hr. PRE-CLEAN PERMEATE	TIME = 300 hr. POST-CLEAN PERMEATE
COND.	6%	23%	17%	3%	5%
TURB.	100%	93%	95%	98%	98%
TOC	N/A	72%	54%	52%	44%
COLOUR	N/A	87%	79%	80%	78%
CALCIUM	10%	49%	37%	17%	6%
MAGNESIUM	47%	61%	49%	12%	12%
HARDNESS	24%	54%	42%	15%	8%
SILICA	0%	0%	0%	0%	0%

3.6.3 Test #3 Site C, Skim Tank

The sample used during this test was obtained from the skim tank in the produced water treatment process from Site "C".

The results for the flux rates obtained during this test are shown in Figure 3-17. Initially, the flux rate for PSC-C was approximately 4 m^3/m^2/day but decreased to 3 m^3/m^2/day during concentration to a 90% volume reduction (10 fold concentration factor). The flux rate decreased further to 1.0 m^3/m^2/day and remained stable at that level for 150 hours of operation. After cleaning the flux rate increased back up to over 3.0 m^3/m^2/day then stabilized at 2.5 m^3/m^2/day. The flux rate for membrane CHP-TFC was initially lower than for PSC-C and remained lower throughout the run.

The initial sample of emulsion was very stable and showed virtually no sign of breaking spontaneously. During concentration, some free oil was observed floating on the surface of the process tank. As the system was operated in a recycle mode, the emulsion was subjected to a considerable amount of aeration and elevated temperature for an extended period of time (over 150 hr). During this time, more and more free oil was observed floating in the process tank. Oil was removed during this time until virtually all the emulsified oil had been removed as free oil. As this oil was removed, the concentrated produced water turbidity decreased from 2,200 NTU to 27 NTU. The concentrate did however, retain considerable colour (1,200 APHA units) at this point in time.

The free oil is thought to have contributed to the lower flux rate observed in this test as compared with tests with other produced water emulsions. This low emulsion stability, relative to

FIGURE 3 - 17

FLUX RATE VS TIME
for Test #3, Site C, Skim Tank

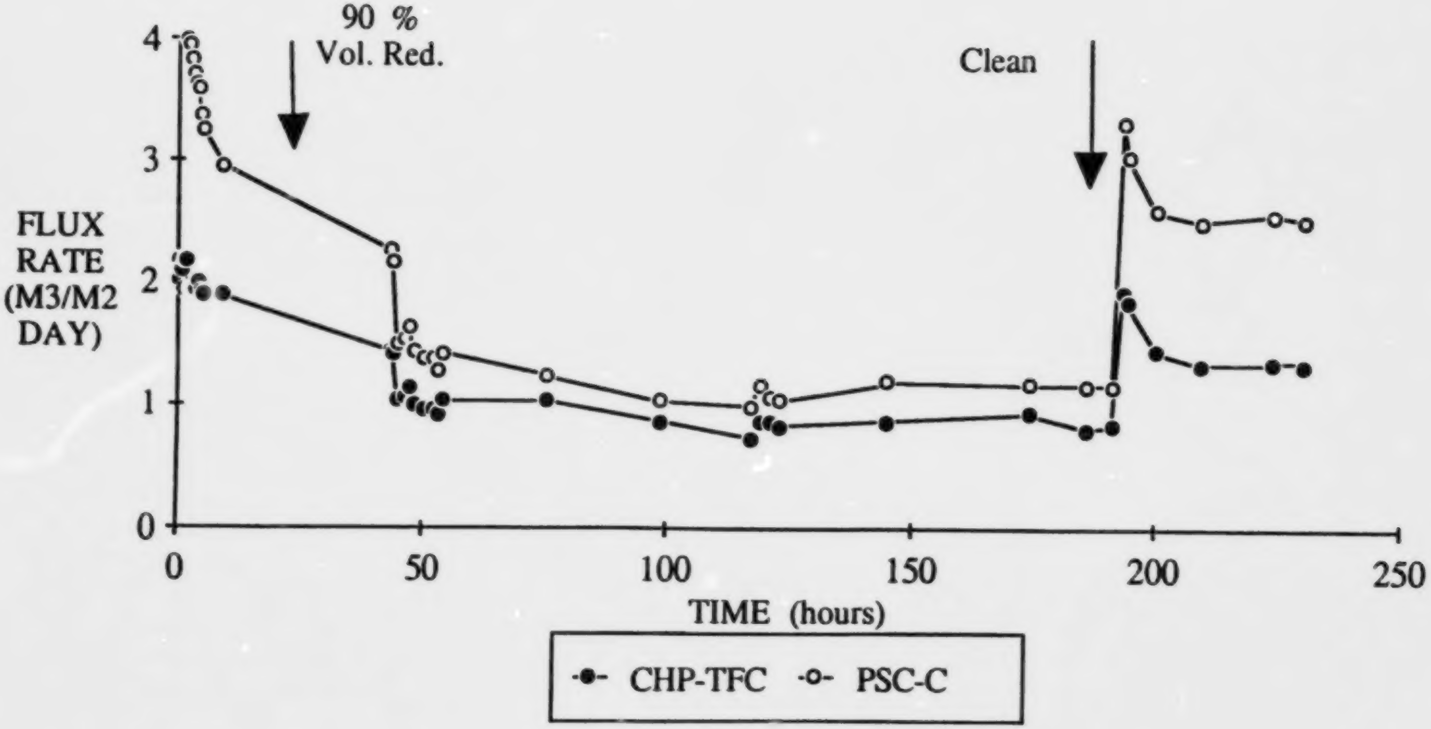


TABLE 3 - 33

PERMEATE QUALITY FOR TEST #3 SITE C, Skim Tank

DATE: JUNE 24, 1986 MEMBRANE: CHP - TFC / PSC - C

PARAMETER	UNITS	RAW FEED	TIME = 18 hr. -- 90% VOL. REDUCTION			TIME = 200 hr. -- POST CLEANING			TIME = 230 hr. -- END OF RUN		
			CONC.	PERMEATE CHP - TFC	PERMEATE PSC - C	CONC.	PERMEATE CHP - TFC	PERMEATE PSC - C	CONC.	PERMEATE CHP - TFC	PERMEATE PSC - C
pH		6.45	7.30	7.13	7.44	8.57	7.00	6.65	7.76	7.32	7.32
COND.	umho	5.69	6.45	5.63	6.09	7.55	7.28	7.26	8.03	7.78	7.94
TURB.	NTU	250	2,200	6.0	6.8	400	11.0	11.0	27	4.8	3.5
TOC	mg/L	N/A	110	90	120	160	130	150	180	N/A	N/A
COLOUR	APHA	1,500	20,000	250	400	3,500	750	800	1,200	800	900
CALCIUM	mg/L	59	84	51	59	47	46	44	40	N/A	N/A
MAGNESIUM	mg/L	7.9	12.0	7.6	8.1	8.7	6.9	7.5	5.2	N/A	N/A
HARDNESS	mg/L	180	259	159	181	153	143	141	121	N/A	N/A
SILICA	mg/L	36	160	54	52	25	21	23	21	N/A	N/A

N/A - Not Available

TABLE 3 - 34

PERCENT REJECTION FOR TEST #3 SITE C, Skim Tank

DATE: JUNE 24, 1986 MEMBRANE: CHP - TFC / PSC - C

PARAMETER	TIME = 18 hr 90% V.R. CHP - TFC	 PSC - C	TIME = 200 hr POST CLEANING CHP - TFC	 PSC - C	TIME = 230 hr END OF RUN CHP - TFC	 PSC - C
COND.	13%	6%	4%	4%	3%	1%
TURB.	100%	100%	97%	97%	82%	87%
TOC	18%	0%	19%	6%	N/A	N/A
COLOUR	99%	98%	79%	77%	33%	25%
CALCIUM	39%	30%	2%	6%	N/A	N/A
MAGNESIUM	37%	33%	21%	14%	N/A	N/A
HARDNESS	39%	30%	6%	8%	N/A	N/A
SILICA	66%	68%	16%	8%	N/A	N/A

N/A - Not Available

other samples, is thought to be a result of different natural and added surfactant materials present in different samples of produced water.

The permeate generated in the membrane process was free of all suspended oil and solids and showed some reduction in hardness. Table 3-33 shows the feed and permeate quality for both membranes during the test and Table 3-34 shows the % rejections for various components.

The turbidity of the permeate from PSC-C at a 90% volume reduction (a 10 fold concentration factor) was measured at 6.8 NTU vs. the feed at 250 NTU and the concentrate at 2,200 NTU. The residual measured turbidity of 6.8 NTU is not as a result of suspended material but is due to residual colour present in the sample. The residual colour in the permeate was measured at 400 alpha units vs. 1,500 in the feed and 20,000 in the concentrate and the residual level of organic in the permeate as measured by total organic carbon (TOC) was 120 mg/L. Calcium, magnesium, and silica were also reduced somewhat by the membrane but further hardness reduction will be required to meet the criteria for the once through boilers.

3.6.4 Test #4 Site D, Skim Tank

The sample of produced water used during this test was obtained from the skim tank from site "D" in Western Canada.

The flux rate results from the test performed with this sample are shown in Figure 3-18. The initial flux rate with membrane PSC-C was about 6 m^3/m^2/day and decreased to between 4 and 5 m^3/m^2/day during concentration to a 90% volume reduction. The flux rate was

FIGURE 3 - 18

FLUX RATE VS TIME
for Test #4, Site D, Skim Tank

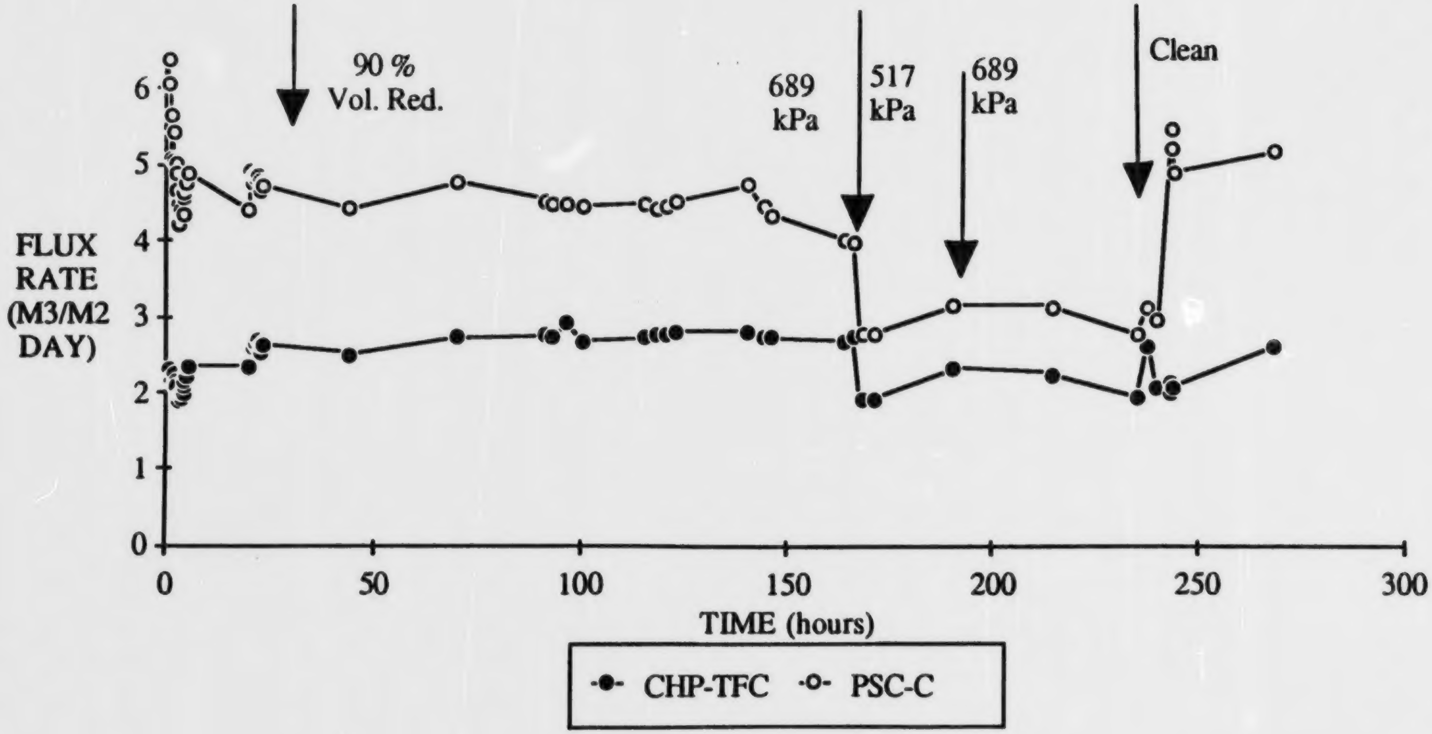


TABLE 3 - 35

PERMEATE QUALITY FOR TEST #4 SITE D, Skim Tank

DATE: AUG. 1, 1986 MEMBRANE: CHP - TFC / PSC - C

PARAMETER	UNITS	RAW FEED	TIME = 25 hr -- 90% VOLUME REDUCTION			TIME = 250 hr -- POST CLEAN	
			CONC.	PERMEATE CHP - TFC	PERMEATE PSC - C	PERMEATE CHP - TFC	PERMEATE PSC - C
pH		6.43	6.90	7.90	8.32	7.04	7.34
COND.	umho	44.7	46.2	45.3	45.0	60.0	59.0
TURB.	NTU	180	3,650	1.9	0.8	3.4	3.4
TOC	mg/L	N/A	N/A	44	50	69	45
COLOUR	APHA	N/A	12,500	125	225	150	300
CALCIUM	mg/L	600	580	680	710	750	780
MAGNESIUM	mg/L	280	280	270	270	340	360
HARDNESS	mg/L	2,651	2,601	2,809	2,884	3,272	3,429
SILICA	mg/L	17	22	26	25	15	16

TABLE 3 - 36

PERCENT REJECTIONS FOR TEST #4 SITE D, Skim Tank

DATE: AUG. 1, 1986 MEMBRANE: CHP - TFC / PSC - C

	TIME = 25 hr -- 90% V.R.		TIME = 250 hr -- POST CLEAN	
PARAMETER	CHP - TFC	PSC - C	CHP - TFC	PSC - C
COND.	2%	3%	0%	0%
TURB.	100%	100%	100%	100%
COLOUR	99%	98%	99%	98%
CALCIUM	0%	0%	0%	0%
MAGNESIUM	4%	4%	0%	0%
HARDNESS	0%	0%	0%	0%
SILICA	0%	0%	32%	27%

stable at that level for 150 hours. At the 166 hour mark, the applied membrane pressure was decreased from 689 kPa (100 psi) to 517 kPa (75 psi). The flux rate as expected decreased to 2.8 m^3/m^2/day as the driving force through the membrane decreased. At the 190 hour mark the pressure was increased back up to 689 kPa (100 psi) but the flux rate did not increase until the system was cleaned at 240 hours. After cleaning, the flux increased to above 5 m^3/m^2/day where it remained stable for the remainder of the test.

The flux rate for membrane CHP-TFC was only about 2.5 m^3/m^2/day during operation at 689 kPa (100 psi) and remained lower than for the PSC-C throughout the test. The permeate generated in the membrane process was free of all suspended oil and solids and showed some reduction in hardness. Table 3-35 shows the feed and permeate quality for both membranes during the test and Table 3-36 shows the % rejections for various components.

The turbidity of the permeate from PSC-C at 90% volume reduction (a 10 fold concentration factor) was measured at 0.8 NTU vs. the feed at 180 NTU and the concentrate at 3,650 NTU. The residual colour in the permeate was measured at 225 APHA unit vs. 20,000 in the concentrate. The residual level of organics in the permeate as measured by total organic carbon (TOC) was 50 mg/L. Calcium, magnesium, and silica were also reduced somewhat by the membrane but again further hardness reduction with be required to meet the criteria for the once through boilers.

3.6.5 Test #5 Site E, Skim Tank

The sample of produced water used during this test was obtained from the skim tank at Site "E".

The results for the flux rates obtained during this test are shown in Figure 3-19. Initially, the flux rates for both CHP-TFC and PSC-C membranes were approximately 3 m^3/m^2/day but decreased to 1.1 m^3/m^2/day during concentration to an 85% volume reduction. After cleaning the flux rate increased to 2.5 m^3/m^2/day then decreased to 1.1 m^3/m^2/day.

The initial sample of emulsion was stable and showed no sign of breaking spontaneously. During the run, the emulsion was subjected to a considerable amount of aeration and elevated temperature and some free oil was observed floating on the surface of the process tank. The free oil again is thought to have contributed to the low flux rate observed in this test as compared with tests with other produced water emulsions.

The permeate generated in the membrane process was free of all suspended oil and solids and showed some reduction in hardness. Table 3-37 shows the feed and permeate quality for both membranes during the test and Table 3-38 shows the % rejections for various components.

The turbidity of the permeate from PSC-C at a 90% volume reduction (a 10 fold concentration factor) was measured at 50 NTU vs. the feed at 100 NTU and the concentrate at 3,400 NTU. The residual colour in the permeate was measured at 375 APHA units vs. 1,250 in the feed and 35,000 in the concentrate and the residual level of organic in the permeate as measured by total organic carbon (TOC) was 110

FIGURE 3 -19

FLUX RATE VS TIME
for Test #5, Site E, Skim Tank

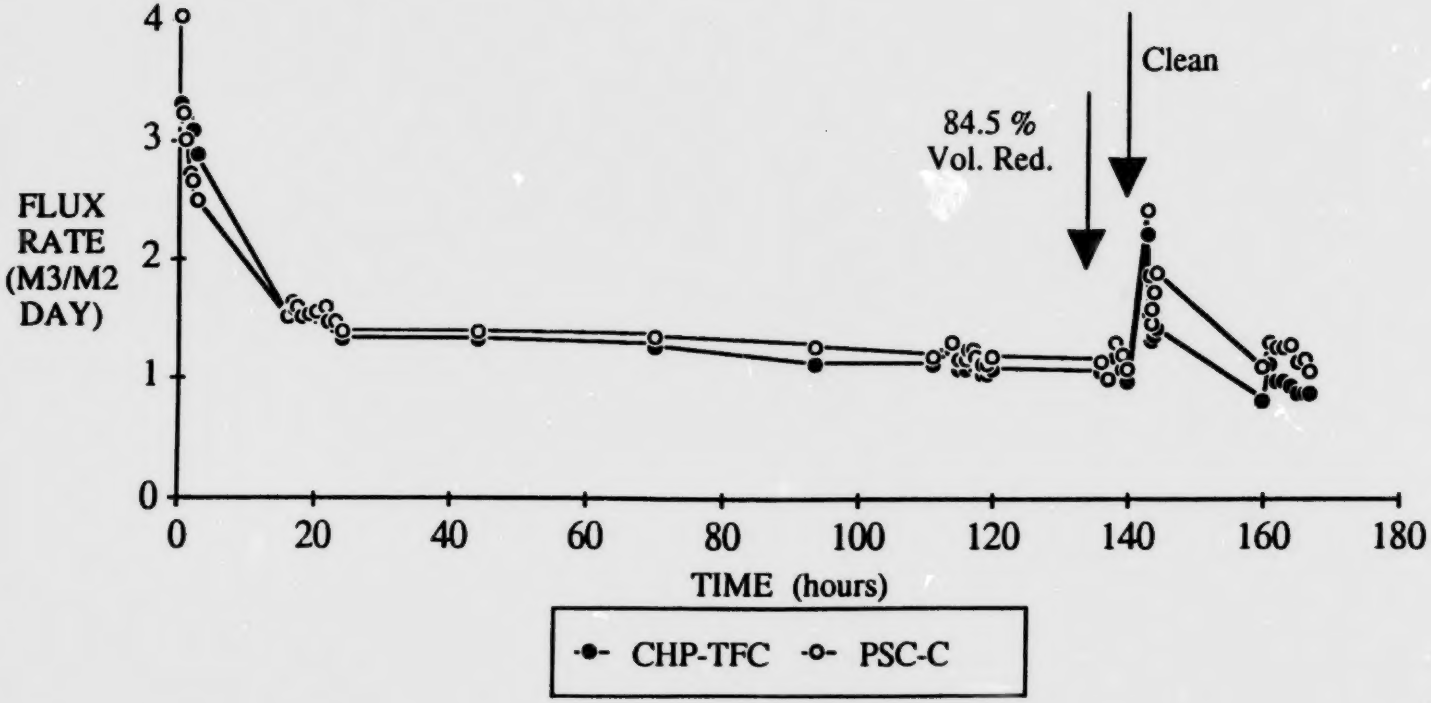


TABLE 3 - 37

PERMEATE QUALITY FOR TEST #5 SITE E, Skim Tank

DATE: AUG. 28, 1986 MEMBRANE: CHP - TFC / PSC - C

PARAMETER	UNITS	RAW FEED	TIME = 138 hr. -- 85% VOL. REDUCTION			TIME = 142 hr. - POST CLEAN	
			CONC.	PERMEATE CHP - TFC	PERMEATE PSC - C	PERMEATE CHP - TFC	PERMEATE PSC - C
pH		8.90	9.05	8.67	8.71	8.82	8.89
COND.	umho	9.01	12.11	9.47	9.54	11.83	11.44
TURB.	NTU	100	3,400	3.8	5.0	17.4	11.2
TOC	mg/L	N/A	N/A	91	110	320	260
COLOUR	APHA	1,250	35,000	325	375	4,500	3,000
CALCIUM	mg/L	74	200	49	47	61	54
MAGNESIUM	mg/L	8.3	18.0	3.9	3.6	1.5	1.3
HARDNESS	mg/L	219	573	138	132	158	140
SILICA	mg/L	68	550	65	70	70	65

N/A - Not Available

TABLE 3 - 38

PERCENT REJECTION FOR TEST #5 SITE E, Skim Tank

DATE: AUG. 28, 1986

MEMBRANE: CHP - TFC / PSC - C

PARAMETER	TIME = 138 hr. 85% VOL. RED.		TIME = 142 hr. POST CLEAN	
	CHP - TFC	PSC - C	CHP - TFC	PSC - C
COND.	22%	21%	2%	6%
TURB.	100%	100%	99%	100%
COLOUR	99%	99%	87%	91%
CALCIUM	76%	77%	70%	73%
MAGNESIUM	78%	80%	92%	93%
HARDNESS	76%	77%	72%	76%
SILICA	88%	87%	87%	88%

N/A - Not Available

Rejections are based on values in the Concentrate at Time = 138 hr.

mg/L. Calcium, magnesium, and silica were also reduced somewhat by the membrane but further hardness reduction will be required before use as boiler feedwater.

3.6.6 Test #6 Site F, FWKO

The sample of produced water used during this test was obtained from the free water knock out (FWKO) tank of a treatment process at Site "F".

The results for the flux rates obtained during this test are shown in Figure 3-20. Initially, the flux rates for both membranes were approximately 6 m^3/m^2/day and decreased to 2 m^3/m^2/day during concentration to a 90% volume reduction. The flux rates remained stable at that level for about 40 hours until the system was cleaned. After cleaning the flux rate increased to 5 - 6 m^3/m^2/day then decreased slowly during the following 4 days down to about 3 m^3/m^2/day.

The permeate generated in the membrane process was free of all suspended oil and solids and showed some reduction in hardness. Table 3-39 shows the feed and permeate quality during the test and Table 3-40 shows the % rejections for various components.

The turbidity of the permeate at a 90% volume reduction (a 10 fold concentration factor) was measured at 2 NTU vs. the feed at 105 NTU and the concentrate at 2,600 NTU. The residual colour in the permeate was measured at 400 APHA units vs. 500 in the feed and 20,000 in the concentrate and the residual level of organic in the permeate as measured by total organic carbon (TOC) was 83 mg/L. Calcium, magnesium, and silica were also reduced somewhat by the membrane but

FIGURE 3 - 20

FLUX RATE VS TIME
for Test #6, Site F, FWKO

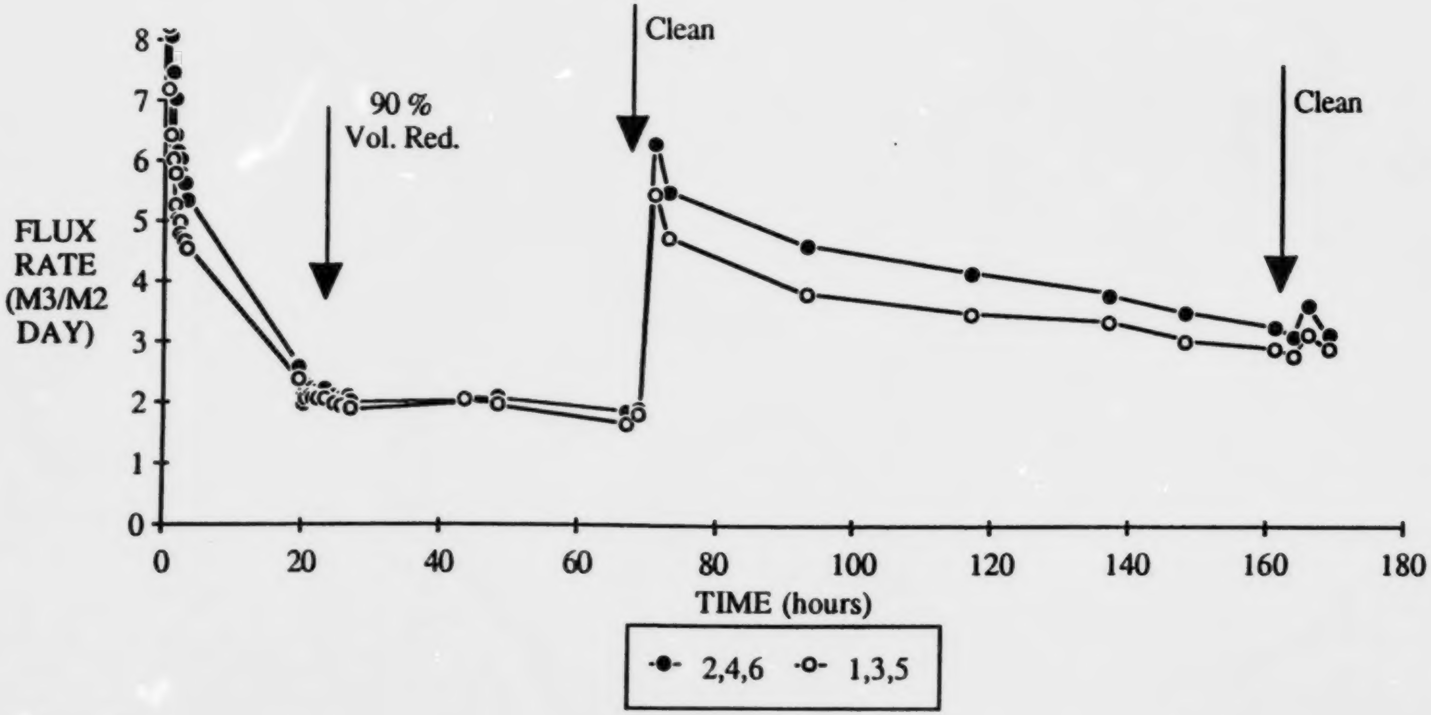


TABLE 3 - 39

PERMEATE QUALITY FOR TEST #6 SITE F, FWKO

DATE: SEPT. 9, 1986 MEMBRANE: PSC - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 24 hr.	TIME = 24 hr.		TIME = 69 hr.	TIME = 71 hr.
		RAW FEED	COMPOSITE PERMEATE	90 % Vol. Red. CONC.	90 % Vol. Red. PERMEATE	PRE-CLEAN PERMEATE	POST CLEAN PERMEATE
pH		6.13	8.20	8.24	8.20	7.80	7.73
COND.	umho	17.80	19.86	20.93	20.32	22.10	24.50
TURB.	NTU	105	5	2,600	2	4	7
TOC	mg/L	N/A	78	N/A	83	N/A	N/A
COLOUR	APHA	500	500	20,000	400	500	475
CALCIUM	mg/L	300	280	290	270	N/A	N/A
MAGNESIUM	mg/L	120	130	140	120	N/A	N/A
HARDNESS	mg/L	1,243	1,300	1,234	1,168	N/A	N/A
SILICA	mg/L	36	64	44	45	N/A	N/A

N/A - Not Available

TABLE 3 - 40

PERCENT REJECTION FOR TEST #6 SITE F, FWKO

DATE: SEPT. 9, 1986 MEMBRANE: PSC - C

PARAMETER	TIME = 24 hr. 90 % Vol. Red.	TIME = 69 hr. PRE-CLEAN	TIME = 71 hr. POST CLEAN
COND.	3%	0%	0%
TURB.	100%	100%	100%
COLOUR	98%	98%	98%
CALCIUM	7%	N/A	N/A
MAGNESIUM	14%	N/A	N/A
HARDNESS	5%	N/A	N/A
SILICA	0%	N/A	N/A

N/A - Not Available
Rejections are Based on values in the concentrate at Time = 24 hr.

further hardness reduction will be required before use as boiler feedwater.

3.6.7 Test #7 Site G, FWKO & HTS

The sample of produced water used during this test was obtained from the combined flow of water from the FWKO and HTS at the heavy oil recovery Site "G".

The results for the flux rates obtained during this test are shown in Figure 3-21. Initially, the flux rate was approximately 2.5 m^3/m^2/day and decreased to 2.0 m^3/m^2/day where it stabilized for 140 hours of operation. After cleaning, the flux rate increased to 3.0 m^3/m^2/day and remained stable at that level for the remaining 25 hours of operation.

This sample had been filtered as it was collected and contained very little free oil or suspended material but was highly coloured. Testing with samples from other field locations where considerably more emulsified oil was present demonstrated that stable flux rates of 3 - 4 m^3/m^2/day could be obtained. This suggests that the quantity of emulsified oil present in a produced water may not be as important as other characteristics in determining the flux rates which can be obtained. Site specific testing will need to be conducted to evaluate the factors which actually determine the flux rates which can be generated.

The permeate generated in the membrane process showed a considerable reduction in colour and turbidity and showed some reduction in hardness. Although oil was not measured directly, the clarity of the permeate generated indicates that all suspended oil and

FIGURE 3 - 21

FLUX RATE VS TIME
for Test #7, Site G, FWKO & HTS

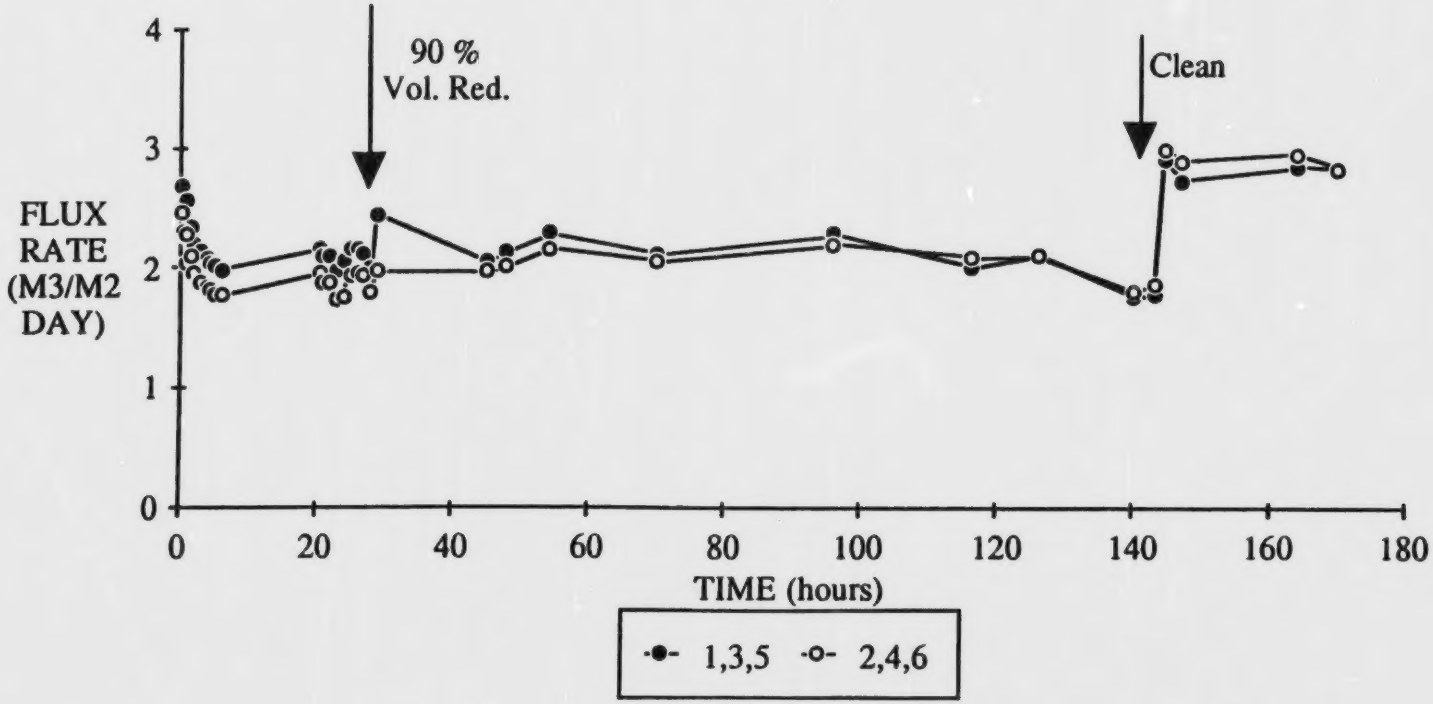


TABLE 3 - 41

PERMEATE QUALITY FOR TEST #7, SITE G, FWKO & HTS

DATE: SEPT. 24, 1986 MEMBRANE: PSC - C

PARAMETER	UNITS	TIME = 0 hr.		TIME = 0 - 29 hr.	TIME = 29 hr.	TIME = 143 hr.	TIME = 145 hr.	TIME = 170 hr.
		INITIAL FEED	INITIAL PERMEATE	COMPOSITE PERMEATE	90 % Vol. Red. CONCENTRATE	PRE-CLEAN PERMEATE	POST-CLEAN PERMEATE	FINAL PERMEATE
pH		8.85	8.10	8.32	8.54	8.17	8.34	8.48
COND.	umho	2.90	1.95	2.56	5.93	4.15	4.15	3.26
TURB.	NTU	240	10	8	1,100	8	9	7
COLOUR	APHA	2,500	500	450	3,000	900	850	325
CALCIUM	mg/L	26.0	5.7	5.6	100.0	N/A	N/A	6
MAGNESIUM	mg/L	5.0	1.4	1.7	11.0	N/A	N/A	2
HARDNESS	mg/L	86	20	21	295	N/A	N/A	22
SILICA	mg/L	93	100	130	540	N/A	N/A	150

N/A - Not Available

TABLE 3 - 42

PERCENT REJECTION FOR TEST #7 SITE G, FWKO & HTS

DATE: SEPT. 24, 1986 MEMBRANE: PSC - C

PARAMETER	TIME = 0 hr. INITIAL	TIME = 0 - 29 hr COMPOSITE	TIME = 143 hr. PRE-CLEAN	TIME = 145 hr. POST-CLEAN	TIME = 170 hr. FINAL
COND.	33%	12%	30%	30%	45%
TURB.	96%	97%	99%	99%	99%
COLOUR	80%	82%	70%	72%	89%
CALCIUM	78%	78%	N/A	N/A	N/A
MAGNESIUM	72%	66%	N/A	N/A	-18%
HARDNESS	77%	75%	N/A	N/A	-5%
SILICA	0%	0%	N/A	N/A	72%

For Time = 0 and Time = 0 - 29 hr., Rejection is Based on Initial Feed. For All Others Rejection is Based on 90 % Vol. Red. concentrate.

N/A - Not Available

solids are removed. Table 3-41 shows the feed and permeate quality during the test and Table 3-42 shows the % rejections for various components.

The turbidiy of the composite permeate taken during concentration to a 90% volume reduction (a 10 fold concentration factor) was measured at 10 NTU vs. the feed at 240 NTU. The residual colour in the composite permeate was measured at 450 APHA units vs. 2,500 in the feed. Calcium, magnesium, and silica were also reduced somewhat by the membrane but further hardness reduction will be required before use as boiler feedwater.

The composite permeate collected during concentration measurements are most significant since this would be the actual product quality in a large system operated in an automated batch mode.

3.7 Testing with Different Emulsions at Devon, Alberta

Table 3-43 shows the characteristics of the five produced water samples used in this set of experiments. The samples used for these tests were obtained and used within 24 to 72 hours of the samples being collected.

3.7.1 Test D1, Site F, FWKO

The sample used for this test was obtained from the FWKO in the produced water treatment process at site "F". Some small amount of free oil had adhered to the side of the barrel in which the sample had been collected. The sample had a greyish/blue colour and had suspended solids present which did not readily settle. A strong H_2S

TABLE 3 - 43

RAW FEED CHARACTERISTICS FOR DEVON TESTING

PARAMETER	D1 SITE F HTS	D2 SITE E Wellhead	D3 SITE E IGF	D4 SITE H FWKO	D5 SITE D FWKO
pH	N/A	N/A	7	7	8
TDS (mg/L)	12,000	7,410	7,630	45,400	13,200
TDO (mg/L)	730	1,120	890	2,600	640
TSS (mg/L)	790	2,320	410	440	220
TSO (mg/L)	230	1,230	31	28	100
TURBIDITY (NTU)	15	7,000	3	24	180
COLOUR (APHA)	N/A	N/A	500	1,300	2,250
CONDUCTIVITY (umho)	17	11	9	59	18
HARDNESS (mg/L)	1,143	149	205	3,713	1,002
EXTRACTABLE OILS (mg/L)	360	>1000	4	18	64
ANIONS (mg/L)					
Bromide	<8	<8	<8	73.0	21.0
Chloride	7,000	5,000	4,100	17,000	6,300
Fluoride	<1	<1	<1	<1	<1
Nitrate (as N)	<2	4	3	<2	<2
Nitrite (as N)	<2	<2	<2	<2	<2
Phosphate (as P)	<8	<8	<8	<8	<8
Sulfate	59	11	87	41	87
CATIONS (mg/L)					
Aluminum	<0.3	<0.3	<0.3	<0.3	<0.3
Barium	7	0	0	3	4
Beryllium	<0.003	<0.003	<0.003	<0.003	<0.003
Boron	24	51	51	13	18
Cadmium	<0.02	<0.02	<0.02	<0.02	<0.02
Calcium	260	58	66	630	220
Chromium	<0.04	<0.04	<0.04	<0.04	1
Cobalt	<0.1	<0.1	<0.1	<0.1	<0.1
Copper	<0.06	<0.06	<0.06	<0.06	4
Iron	6	2	9	0	1
Lead	<0.4	<0.4	<0.4	<0.4	<0.4
Magnesium	120	10	10	520	110
Manganese	1	0	0	1	0
Molybdenum	<0.2	<0.2	<0.2	<0.2	<0.2
Nickel	<0.09	<0.09	<0.09	<0.09	<0.09
Phosphorous	<1	5	<1	1	<1
Potassium	120	100	83	310	96
Silica	46	88	80	5	37
Silver	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium	3,600	2,700	2,700	16,200	4,400
Strontium	20	2	1	37	18
Thallium	<0.2	<0.2	<0.2	<0.2	<0.2
Titanium	<0.1	<0.1	<0.1	<0.1	<0.1
Vanadium	<0.2	<0.2	<0.2	<0.2	<0.2
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05
Zirconium	<0.1	<0.1	<0.1	<0.1	<0.1

TDS - TOTAL DISSOLVED SOLIDS	TSS - TOTAL SUSPENDED SOLIDS
TDO - TOTAL DISSOLVED OILS	TSO - TOTAL SUSPENDED OILS

smell was observed when the sample was transferred to the process tank.

At the start of the test the process tank was charged with 40 L of produced water which was recirculated through the pump bypassing the membranes until the temperature reached 65°C. During this time there was considerable aeration of the produced water and some free oil and froth was skimmed from the process tank. Once the temperature reached 65°C, flow was directed through the membrane module. Permeate was then removed from the system and additional produced water was added to the process tank to keep the tank at its 40 L capacity until a total of 110 L had been added to the tank.

The initial flux rates for the system, as shown in Figure 3-22, were very high, well above 5 m^3/m^2/day, but decreased during the first 3 hours of operation and concentration to 47.6% volume reduction (CF = 1.9) to about 3 m^3/m^2/day. The system was left overnight with no further concentration taking place and the flux rate declined to just under 1.75 m^3/m^2/day by the following morning. During concentration on the second day (19.75 hours to 26.5 hours) to a volume reduction of 63.45% (CF = 2.7) the flux declined slightly to 1.4 m^3/m^2/day. Over the second night with no concentration the flux declined to 1.14 m^3/m^2/day then stabilized at 1.2 m^3/m^2/day during final concentration to a volume reduction of 90.9% (CF of 10.9). The flux rate remained stable at 1.2 m^3/m^2/day for the following 64 hours while the system was operated in a recycle mode. No sign of emulsion breaking was observed upon concentration to this level.

FIGURE 3 - 22

FLUX RATE VS TIME
for Test #D1, SITE F, HTS

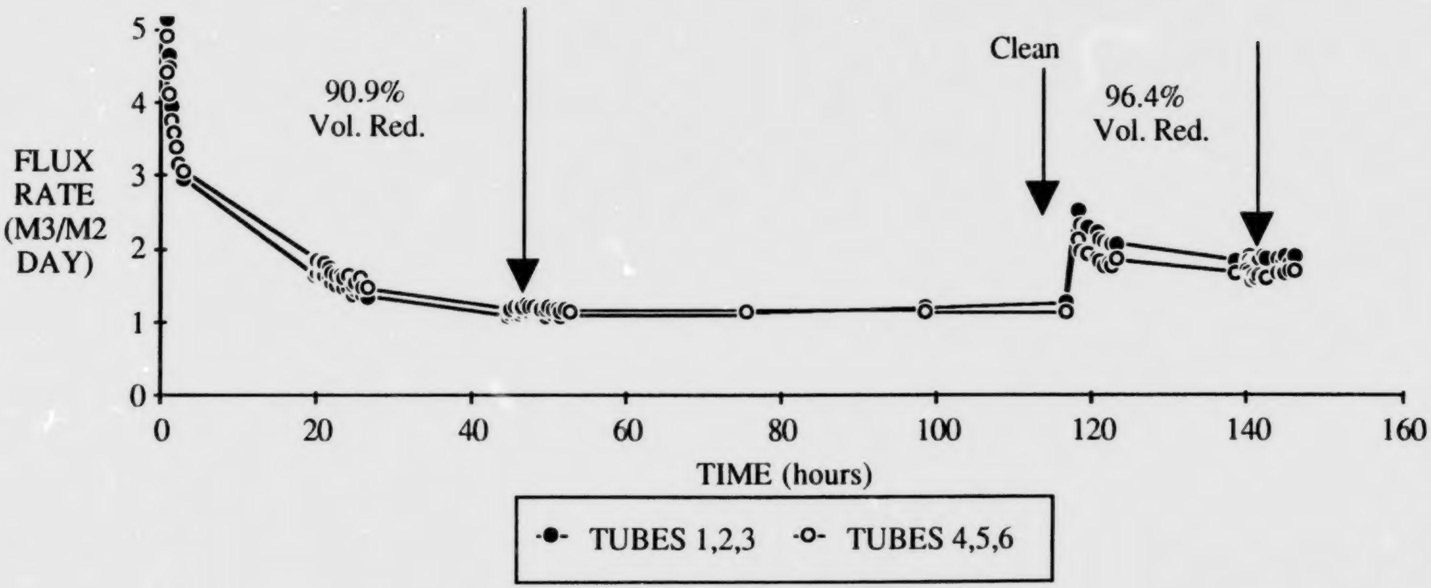


TABLE 3 - 44

PERMEATE QUALITY FOR TEST #D1, SITE F, HTS

DATE: OCTOBER 27, 1986 MEMBRANE: FLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 52.5 hr.	TIME = 52.5 hr.		TIME = 116.5 hr.	TIME = 118 hr.	TIME = 141.5 hr.	
		RAW FEED	COMPOSITE PERMEATE	90% Vol. Red. CONC.	90% Vol. Red. PERMEATE	PRE-CLEAN PERMEATE	POST CLEAN PERMEATE	96% Vol. Red. CONC.	96% Vol. Red. PERMEATE
pH		N/A	7.69	8.28	8.23	8.35	8.39	8.50	8.40
COND.	umho	16.67	15.94	17.50	16.53	17.47	17.19	N/A	17.41
TURB.	NTU	15	1.2	4,000	N/A	N/A	N/A	N/A	N/A
COLOUR	APHA	N/A	375	30,000	150	250	350	40,000	425
CALCIUM	mg/L	260	260	300	N/A	N/A	N/A	N/A	N/A
MAGNESIUM	mg/L	120	120	130	N/A	N/A	N/A	N/A	N/A
HARDNESS	mg/L	1,143	1,143	1,284	N/A	N/A	N/A	N/A	N/A
SILICA	mg/L	99	88	62	N/A	N/A	N/A	N/A	N/A
EXT. OILS	mg/L	360	<10	570	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

At the 116.5 hour mark the system was cleaned using MC-40i. After cleaning the flux rate increased to 2.3 m^3/m^2/day then declined over the following 22 hours to 1.8 m^3/m^2/day. At this point in time the produced water was further concentrated from a volume reduction of 90.9% to 96.37% over a period of just over one hour. The flux rate remained stable during this final concentration and no sign of emulsion breaking was observed. After the final concentration the system was run in a recycle mode for a further 4.5 hours and the flux remained stable throughout this period of time.

The flux during this test was stable at a level of 1.2 m^3/m^2/day and never dropped significantly below this rate. This level of flux is lower than the 2.0 obtained with a previous sample of produced water from the same Site "F" conducted earlier. Both tests reached a minimum flux rate within several days and the flux never went below this minimum level.

Analytical data for this run are shown in Table 3-44. The turbidity of raw feed was measured at 15 NTU while the composite permeate collected during concentration to a 90.9% volume reduction was only 1.2. This demonstrates a substantial reduction in turbidity. The level of colour in the permeate of 375 alpha units is comparable to the colour of permeates from other tests. The data show virtually no rejection of calcium, magnesium, and silica through the UF membrane.

3.7.2 Test D2 Site E, Wellhead

The sample used for this test was obtained from prior to the FWKO in the produced water treatment process at Site "E".

Considerable free bitumen was present when the initial sample of water was received at Devon. The water fraction of the sample was separated from the oil by pumping the water off from below the layer of floating oil. The sample of water was very dark brown and contained a much higher level of suspended material than previous samples of water taken from further down the treatment process from this and other sites.

As in the previous test an initial charge of 40 L was added to the process tank. As permeate was removed from the system, fresh sample was added to the process tank to keep the tank level at 40 L until a total of 100 L had been added.

The initial flux for the test was as shown in Figure 3-23 above 4.0 m^3/m^2/day but declined to 1.7 m^3/m^2/day during the first 8.0 hours of operation and concentration to a volume reduction of 56.6.% (CF of 2.3). Overnight with no further concentration, the flux declined to 1.3 m^3/m^2/day and during the final 8 hours of concentration to an 84.6% volume reduction (CF of 6.5) the flux decreased to 1.25 m^3/m^2/day. The flux remained stable at this level for 70 hours with no further concentration.

At the 96 hour mark the system was cleaned and the flux rate increased to 2.5 m^3/m^2/day but decreased within a few hours back down to 1.25 m^3/m^2/day where it stayed for the remainder of the test.

As in the previous test the flux rate decreased initially then remained stable for a considerable period of time. This suggests that the membrane fouls with a gel layer which remains throughout the test but once formed prevents additional fouling from further reducing the flux.

FIGURE 3 - 23

FLUX RATE VS TIME
for Test #D2, SITE E, Wellhead

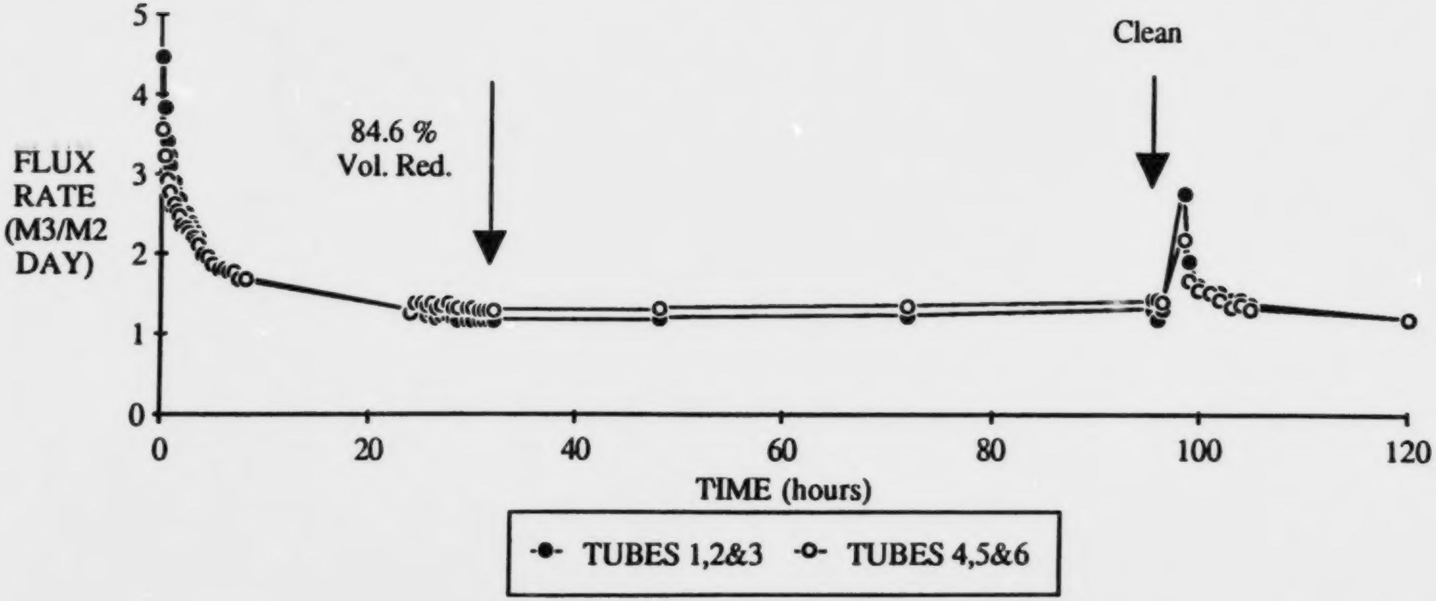


TABLE 3 - 45

PERMEATE QUALITY FOR TEST #D2, SITE E, Wellhead

DATE: OCTOBER 30, 1986 MEMBRANE: FLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 32 hr.	TIME = 32 hr.		TIME = 96.5 hr.	TIME = 98.5 hr.		TIME = 120 hr.
		RAW FEED	COMPOSITE PERMEATE	85% Vol. Red. CONC.	85% Vol. Red. PERMEATE	PRE-CLEAN COMP. PERM.	POST CLEAN TUBES1,2,3	POST CLEAN TUBES4,5,6	COMPOSITE PERMEATE
pH		N/A	8.40	9.00	8.78	8.35	8.95	8.90	8.93
COND.	umho	10.77	10.82	13.34	11.25	17.47	12.61	12.63	12.12
TURB.	NTU	7,000	4.0	15,000	N/A	N/A	N/A	N/A	N/A
COLOUR	APHA	N/A	550	30,000	300	250	1,100	650	425
CALCIUM	mg/L	58	45	65	N/A	N/A	N/A	N/A	N/A
MAGNESIUM	mg/L	10	9	16	N/A	N/A	N/A	N/A	N/A
HARDNESS	mg/L	185	149	228	N/A	N/A	N/A	N/A	N/A
SILICA	mg/L	188	77	34	N/A	N/A	N/A	N/A	N/A
EXT. OILS	mg/L	>1,000	<10	>1,000	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Analytical data for this run are shown in Table 3-45 and demonstrate that the quality of the permeate generated with a feed containing a high concentration of oil is similar to that obtained with the relatively cleaner produced waters from further along in the treatment process. The turbidity of the feed in this test was 7,000 NTU while the composite permeate contained only a small residual turbidity of 4.0 NTU. The colour of the permeate varied between 250-500 alpha units except immediately after cleaning when it deteriorated to 875 alpha units. Throughout all the tests the initial permeate and the permeate generated immediately after cleaning were of poor quality and improved over the following few hours. This is the result of additional filtration of a gel layer on the surface of the membrane or the result of large pores in the membrane being plugged by suspended material during the first few hours of operation. The data again shows very little rejection of inorganic components of calcium, magnesium and silica.

3.7.3 Test D3 Site E, IGF

The sample used for this test was obtained from the induced gas floatation (IGF) unit in the produced water treatment process at Site "E". The sample initially had a yellowish colour and a small amount of black material in suspension. The water was transferred to a second barrel and was left overnight before testing was begun. Overnight the water turned much darker, developed a bluish/purple colour and contained fine black particles in suspension.

As in previous tests, an initial charge of 40 L was added to the process tank. As permeate was removed from the system fresh feed was added to the process tank to keep the tank level at 40 L until a total of 120 L had been added.

The initial flux for the test as shown in Figure 3-24 was above 3.0 m^3/m^2/day but declined quickly to 1.5 during the first 8.5 hours of operation and concentration to a 55.4% volume reduction (CF=2.24). Overnight with no further concentration, the flux decreased to 1.4 m^3/m^2/day. During the following day the water was concentrated to a 66.8% volume reduction (CF=3.0) and the flux decreased to 1.24 m^3/m^2/day. The flux decreased only slightly over the following night and during further concentration to 75.6% volume reduction. At this point the system was cleaned and the flux increased to 1.95 m^3/m^2/day then declined slightly to 1.7 m^3/m^2/day during final concentration to a 91% volume reduction (CF of 11). The flux rate decreased to about 1.4 m^3/m^2/day and remained relatively stable over the following 64.5 hours of operation. The system was cleaned at the 120 hour mark and the flux increased for a very short period of time then declined gradually over 70 hours to 1.13 m^3/m^2/day. At this time sponge ball cleaning of the system was conducted with no effect on membrane flux rate.

The characteristics of the flux rate obtained during this test were very similar to that obtained with a sample of wellhead emulsion from the wellhead of this same site which contained a considerably higher oil level (1,980 mg/L vs. 4 mg/L). These results demonstrate that the flux rate which can be obtained is not a function of the level of oil present. It was thought previously that chemicals added upstream of the skim tank might interfere with the performance of the membrane. These tests indicate that some characteristic

FIGURE 3 - 24

FLUX RATE VS TIME
for Test #D3, SITE E, IGF

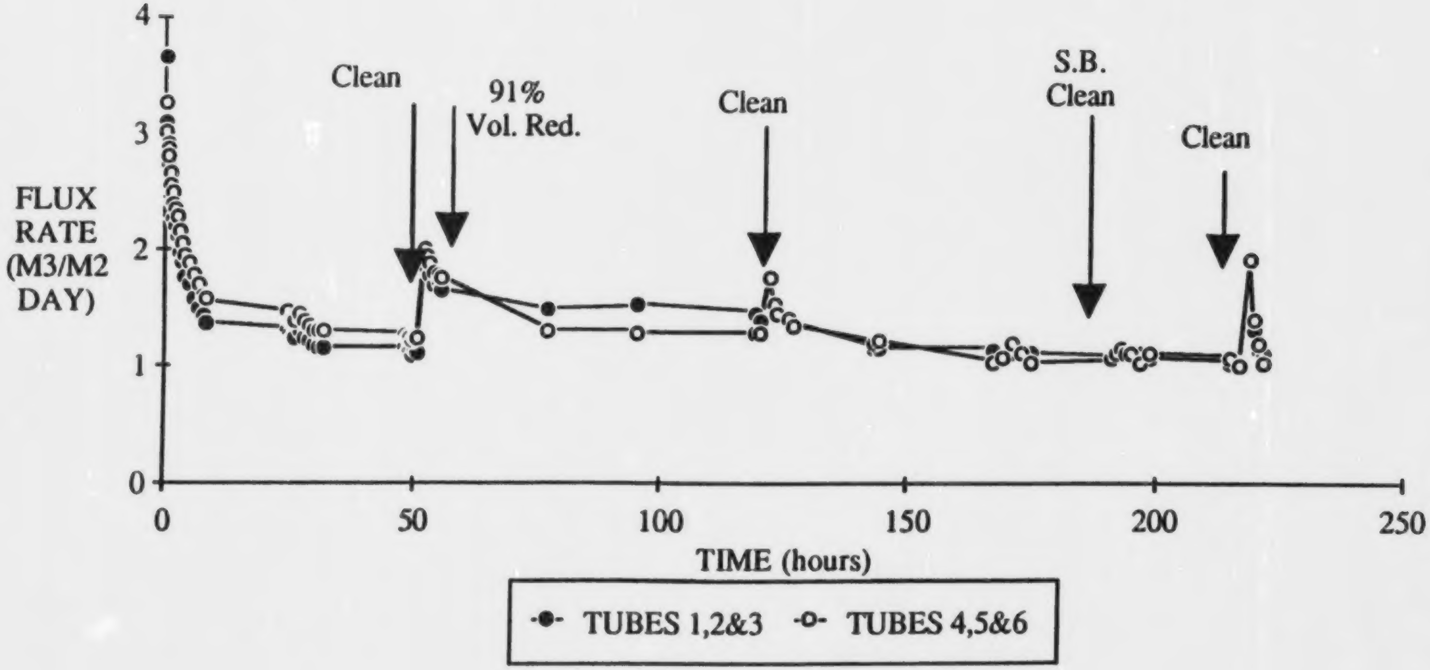


TABLE 3 - 46

PERMEATE QUALITY FOR TEST #D3, SITE E, IGF

DATE: NOVEMBER 5, 1986 MEMBRANE: FLT - C

PARAMETER	UNITS	TIME = 0 hr. RAW FEED	TIME = 0 - 55 hr. COMPOSITE PERMEATE	TIME = 55 hr. 90% Vol. Red. CONC.	TIME = 55 hr. 90% Vol. Red. PERMEATE	TIME = 120 hr. PRE-CLEAN COMP. PERM.	TIME = 122 hr. POST CLEAN PERMEATE	TIME = 192 hr. PRE-CLEAN COMP. PERM.	TIME = 193 hr. POST CLEAN PERMEATE
pH		7.1	8.5	8.6	8.8	8.7	8.8	7.6	7.7
COND.	umho	9.1	9.1	11.3	9.8	9.5	10.0	10.3	10.5
TURB.	NTU	3	1.4	N/A	N/A	N/A	N/A	N/A	N/A
COLOUR	APHA	500	330	17,500	485	625	1,300	750	750
CALCIUM	mg/L	66	56	140	N/A	N/A	N/A	N/A	N/A
MAGNESIUM	mg/L	10	9	20	N/A	N/A	N/A	N/A	N/A
HARDNESS	mg/L	205	179	432	N/A	N/A	N/A	N/A	N/A
SILICA	mg/L	171	114	578	N/A	N/A	N/A	N/A	N/A
EXT. OILS	mg/L	4	15	52	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

interfering with membrane performance is also present in the produced water directly from the wellhead.

Analytical data for this run is shown in Table 3-46. The raw feed for this test had a much lower level of extractable oil (4 mg/L) and colour (500 alpha units) than previous feed samples. Since almost all the oil and suspended solids have already been removed in the IGF process, there is very little residual material for the membrane to remove. The composite permeate collected during concentration contains slightly lower levels of turbidity and colour than the feed. The membrane process is best suited to replace the IGF and filter and therefore treatment of water from the IGF is likely redundant.

Analysis of the concentrate at a 90% volume reduction shows higher levels of turbidity, colour and extractable oils than would be expected by simple concentration of the produced water. It is believed that the combination of concentration and aeration results in changes in the chemistry such that soluble organic compounds precipitate to increase the turbidity and extractable oils present.

The data shows very little reduction in calcium, magnesium and silica but there is a small increase in the amount of these components in the 90% volume reduction concentrate. Mass balances for the three components confirm that the amounts in the concentrate are close to those expected (for magnesium, feed contains; 10 x 100 = 1,000 mg, permeate contains 9 x 90 = 810 mg, and concentrate contains 200 mg).

3.7.4 Test D4 Site H, FWKO

The sample used for this test was obtained from the free water knock out unit in the produced water treatment process at a fire flood operation at site "H". The sample was grey in colour and contained some fine black suspended particulate material.

As in previous tests, an initial charge of 40 L was added to the process tank. As permeate was removed from the system fresh sample was added to the process tank until a total of 116 L had been added to the process tank.

Although identical membranes were used in all tubes in this test, the membranes in the first set of three tubes obtained consistently higher flux rates than membranes in the second set of three tubes. Part of this difference can be explained by the slightly higher average operating pressure of the first set vs. the second. The inlet pressure to the test module is maintained at 793-828 kPa (115-120 psi) while the outlet is between 552-586 kPa (80-85 psi). The average pressure, therefore, in the first set is approximately 103-138 kPa (15-20 psi) greater than that in the second set or 15-20% of the nominal 690 kPa (100 psi) pressure. Even with a linear relationship between pressure and flux this is not sufficient to account for all of the observed difference in flux. Salt flux tests results shown in Appendix H for the membranes used show that the membrane in tube 6 had about half the flux of membranes in the other tubes. This variation in membranes used can account for some of the difference in flux rate as well. For the purpose of discussion, the average flux with the whole module will be used as the system flux rate.

TABLE 3 - 47

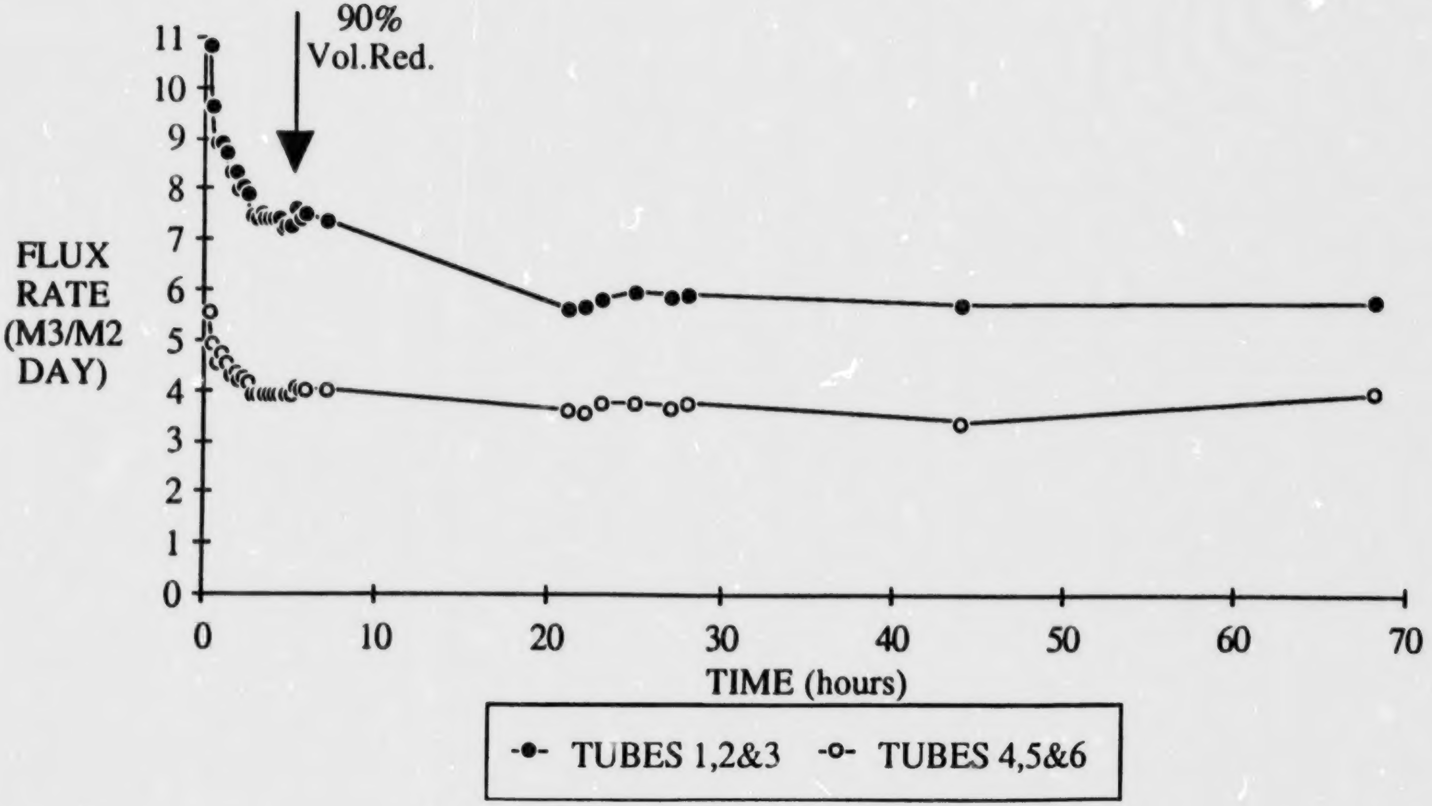
PERMEATE QUALITY FOR TEST #D4, SITE H, FWKO

DATE: NOVEMBER 20, 1986 MEMBRANE: FLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 5.5 hr.	TIME = 5.5 hr.	TIME = 68 hr.
		RAW FEED	COMPOSITE PERMEATE	90% Vol. Red. CONC.	COMPOSITE PERMEATE
pH		6.91	7.30	7.34	8.33
COND.	umho	59.26	59.05	58.95	64.37
TURB.	NTU	24	N/A	42	N/A
COLOUR	APHA	1,300	95	3,300	75
CALCIUM	mg/L	630	550	550	N/A
MAGNESIUM	mg/L	520	520	520	N/A
HARDNESS	mg/L	3,713	3,514	3,514	N/A
SILICA	mg/L	10	13	8	N/A
EXT. OILS	mg/L	18	7	N/A	N/A

N/A - Not Available

FIGURE 3 - 25
FLUX RATE VS TIME
for Test #D4, SITE H, FWKO



The initial system flux as shown in Figure 3-25 was above 8 m^3/m^2/day but declined during the 5.5 hours of concentration to a 90% volume reduction (CF of 10) to 5.75 m^3/m^2/day. The flux rate declined slightly overnight to 4.6 m^3/m^2/day then remained stable at that level for the remaining 47 hours of the run.

The flux during this run was high and stable even while recirculating a feed which had been concentrated by a factor of 10. The feed for this test had an extremely high level of dissolved solids (conductivity 59 umho) and hardness (3,713 mg/L) but a low silica level (10 mg/L). It is apparent that dissolved solids and hardness do not cause poor flux rates.

The analytical data for this run is shown in Table 3-47. The removal of oil and other organic is demonstrated by the reduction of colour and extractable oils. The original colour of the feed was 1,300 and the level in the composite permeates was 95 alpha units. The permeate obtained at the end of the run from a concentrated feed with a colour of 3,300 alpha units was still of a high quality with colour of only 75 alpha units.

The extractable oil level in the feed was 18 mg/L and the level measured in the permeate was 7 mg/L. This level of 7 mg/L in the permeate is higher than anticipated and is believed to be the result of interference from soluble organics absorbed onto the filter paper during analysis. It is unlikely that the permeate having passed through a tight UF membrane with a molecular weight cut off of less than 5,000 would contain any residual oil which should be filtered out with a 0.45 micron filter.

3.7.5 Test D5 Site D, FWKO

The sample used for this test was obtained from the free water knock out (FWKO) unit in the produced water treatment process at site "D". The sample was a muddy brown colour and contained considerable suspended material.

A total of 94 L of raw feed was concentrated as before to a 91.3% volume reduction (CF=11.5). As a result of problems with the temperature control system on the test unit the temperature during this entire run was maintained at 60°C instead of 65°C.

The initial flux for the system as shown in Figure 3-26 was 7.6 m^3/m^2/day but declined during the 6.0 hours of concentration to a 91.3% volume reduction to 3.62 m^3/m^2/day. The flux rate declined overnight to 2.9 m^3/m^2/day then remained stable at that level for the remaining 35.5 hours of the run.

The flux during this run was high and stable even while recirculating a feed concentrated by a factor of over 10. As in the previous run the high dissolved solids level (conductivity of 17.5 umho) and hardness (1000 mg/L) did not interfere with the high flux rates. It is believed that if the system had been operated at a temperature higher than 60°C the flux rate would have increased above the 2.9 m^3/m^2/day obtained in this test.

Analytical data for this run are shown in Table 3-48 and demonstrate a significant reduction in colour and oil with little change in the levels of inorganic components. The colour of the initial feed was 2,250 alpha units while the composite permeate collected during concentration had a colour of only 500 alpha units. The colour of the permeate at the 30 hour mark was 390 alpha units

FIGURE 3 - 26

FLUX RATE VS TIME
for Test #D5, SITE D, FWKO

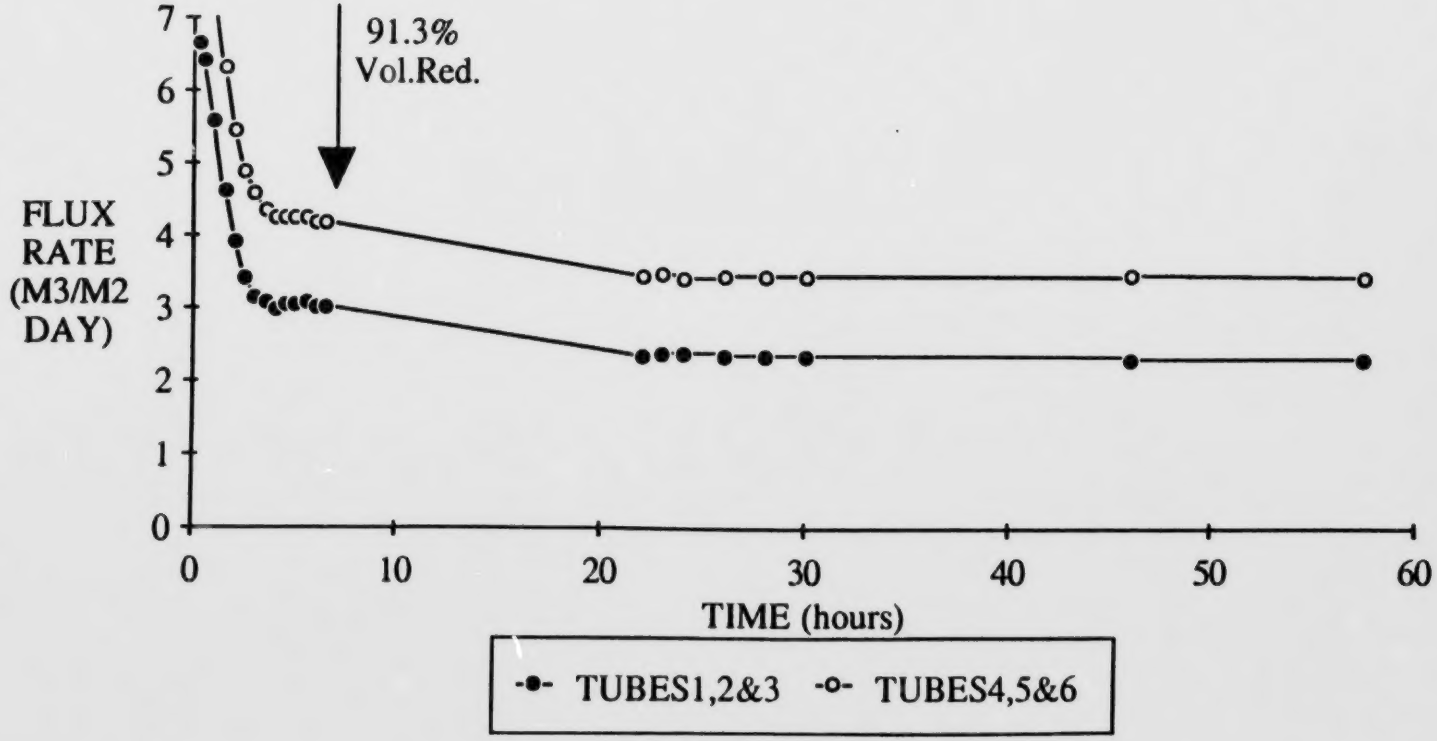


TABLE 3 - 48

PERMEATE QUALITY FOR TEST #D5, SITE D, FWKO

DATE: NOVEMBER 27, 1986 MEMBRANE: FLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 0 - 6.5 hr.	TIME = 6.5 hr.	TIME = 30 hr.	
		RAW FEED	COMPOSITE PERMEATE	91.3% Vol. Red. CONC.	FINAL CONC.	COMPOSITE PERMEATE
pH		7.55	7.30	8.07	8.53	8.22
COND.	umho	17.55	18.30	18.35	18.07	19.13
TURB.	NTU	180	N/A	14	15	N/A
COLOUR	APHA	2,250	500	17,500	17,500	390
CALCIUM	mg/L	220	230	230	N/A	N/A
MAGNESIUM	mg/L	110	120	120	N/A	N/A
HARDNESS	mg/L	1,002	1,068	1,068	N/A	N/A
SILICA	mg/L	79	66	66	N/A	N/A
EXT. OILS	mg/L	64	5	N/A	N/A	N/A

N/A - Not Available

demonstrating that the quality of permeate does not decrease upon concentration. The level of extractable oil was reduced from 64 mg/L in the feed to 5 mg/L in the composite permeate. Again the nature of this "extractable oil" is not entirely clear.

3.8 **In-House Process Optimization**

Polyethylene glycol tests were conducted on three of the membranes used in these tests to determine the molecular weight cut off of the membranes. The results of these tests are shown in Table 3-49 and Figure 3-27. The results show that the FLT-C and HLT-SC membranes have molecular weight cut offs of less than 2,000 while the THLT-C membrane has a larger pore size giving it a 10-20,000 molecular weight cut off.

Raw feed characteristics for the three samples used in this set of testing are shown in Table 3-50. The samples used for these tests were shipped using a quick delivery system so the samples were not more than 7 days old before being used for the first of the tests.

3.8.1 Test #S2-1 Site "D", FWKO

The sample used for this test and the following test #S2-2 was obtained from the FWKO in the produced water treatment process at site "D". Two previous tests with water from this site had shown high and stable flux rates of 3 to 4 m^3/m^2/day. This sample was a dark brown colour but did allow for some light to pass through. No free oil was associated with the sample.

Two membranes of each of three types (FLT-C, FLT-B, & FLT-Q) were used in this and the following #S2-2 test. At the start of this

TABLE 3 - 49

% REJECTION OF PEG OF DIFFERENT MOLECULAR WEIGHTS

MEMBRANE	MOLECULAR WEIGHTS			
	600 M.W.	2,000 M.W.	8,000 M.W.	20,000 M.W.
FLT - C	60%	94%	97%	97%
THLT - C	31%	53%	73%	N/A
HLT - SC	N/A	84%	>95 %	>95 %

FIGURE 3 - 27

PEG Molecular Weight Cut Off Data

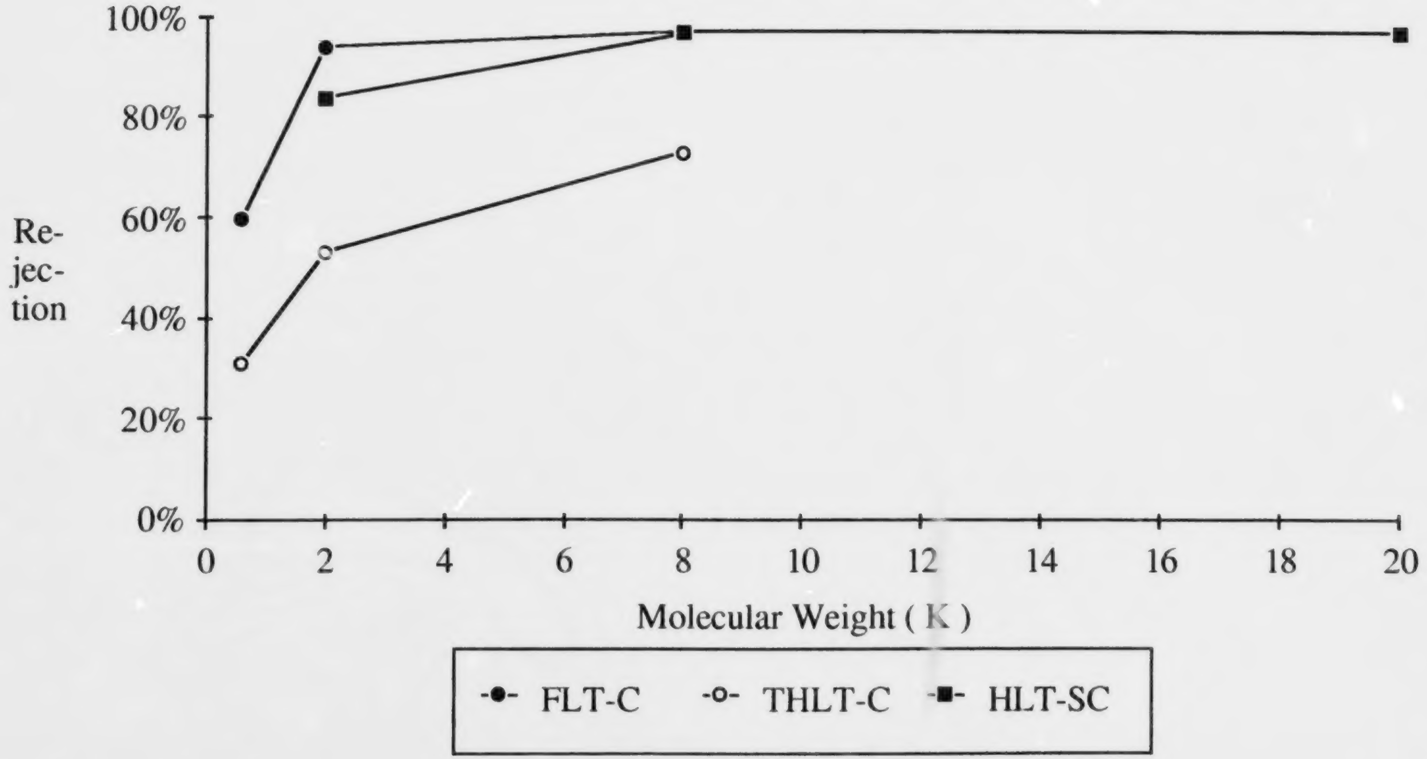


TABLE 3 - 50

RAW FEED CHARACTERISTICS FOR SYSTEM OPTIMIZATION TESTING

PARAMETER	SITE D Skim Tank	SITE E FWKO&HTS	SITE C Skim Tank
pH	7.40	7.35	7.16
TDS (mg/L)	14,000	6,200	9,530
TDO (mg/L)	78	330	430
TSS (mg/L)	2,740	540	68
TSO (mg/L)	1,290	490	120
TURBIDITY (NTU)	16	70	82
COLOUR (APHA)	1,100	7,500	1,750
CONDUCTIVITY (umho)	19.55	7.11	12.18
HARDNESS (mg/L)	1,285	97	257
EXTRACTABLE OILS (mg/L)	25	720	26
OIL (mg/L)	28	640	25
SURFACTANT (mg/L)	18	36	35
ANIONS (mg/L)			
Bromide	<16	8.5	13
Chloride	7,600	3,200	3,800
Fluoride	N/A	N/A	N/A
Nitrate (as N)	<2.0	<0.02	<2.0
Nitrite (as N)	<4.0	<2.0	<2.0
Phosphate (as P)	17	<0.80	<8.0
Sulfate	12	88	46
CATIONS (mg/L)			
Aluminum	<0.03	0.16	<0.03
Barium	5.4	0.27	0.83
Beryllium	<0.0003	<0.0003	<0.0003
Boron	17	44	70
Cadmium	<.002	<0.002	<0.002
Calcium	300	32	94
Chromium	0.025	<0.004	<0.004
Cobalt	<0.01	<0.01	0.031
Copper	<.025	0.011	<0.006
Iron	0.14	0.062	0.091
Lead	<0.04	<0.04	<0.04
Magnesium	130	4.1	5.4
Manganese	0.43	0.052	0.19
Molybdenum	<0.02	<0.02	<0.02
Nickel	<0.009	<0.009	<0.009
Phosphorous	0.98	1.5	2.5
Potassium	74	75	190
Silica	122	195	137
Silver	<0.01	<0.01	<0.01
Sodium	5860	2060	3500
Strontium	23	0.74	1.3
Thallium	<0.02	<0.02	<0.02
Titanium	<0.01	<0.01	<0.01
Vanadium	<0.02	<0.02	<0.02
Zinc	<0.005	0.07	0.047
Zirconium	<0.01	<0.01	<0.02

TDS - TOTAL DISSOLVED SOLIDS
TDO - TOTAL DISSOLVED OILS
TSS - TOTAL SUSPENDED SOLIDS
TSO - TOTAL SUSPENDED OILS

test, 40 L of produced water was added to the process tank and heated to 65°C. The system was operated at a pressure of 345 kPa (50 psi) and a temperature of 65°C for the first 17 hours. The flux for all three membranes as shown in Figure 3-28 and 3-29 were identical throughout the test and started just above 2 m^3/m^2/day then declined to 1.34 m^3/m^2/day during 16 hours of operation. The trans membrane pressure was increased to 517 kPa (75 psi) and the flux increased to 2.1 m^3/m^2/day then decreased to 1.9 m^3/m^2/day. The pressure was then increased to 689 kPa (100 psi) and the flux increased to 2.6 m^3/m^2/day then declined to 2.3 m^3/m^2/day.

The operating temperature was then raised from 65°C to 75°C and the flux initially increased to 2.64 m^3/m^2/day. A flux increase of 0.34 m^3/m^2/day was obtained by increasing the operating temperature 10°C. The flux gradually declined over the following 13.5 hr at 75°C to 1.83 m^3/m^2/day. The temperature was then returned to 65°C and the flux dropped down to 1.5 m^3/m^2/day. The change in flux from decreasing the temperature 10°C was 0.33 m^3/m^2/day.

The system was then cleaned using MC-40i and the produced water was concentrated to a 40% volume reduction with the system operated at 100 psi and 65°C. The flux increased to 2.24 m^3/m^2/day immediately after cleaning then decreased to 1.76 m^3/m^2/day at the end of concentration. The system was then operated in a recycle mode for 17 hours and the flux gradually declined to 1.12 m^3/m^2/day.

The flux rate througout the run to this point had been low and even cleaning with MC-40i did not bring the flux back up to levels obtained in previous tests. It was thought that inorganic fouling may have contributed to the problems observed, so a cleaning was conducted

FIGURE 3 - 28

FLUX RATE VS TIME
for Test #S2-1, SITE D, Skim Tank

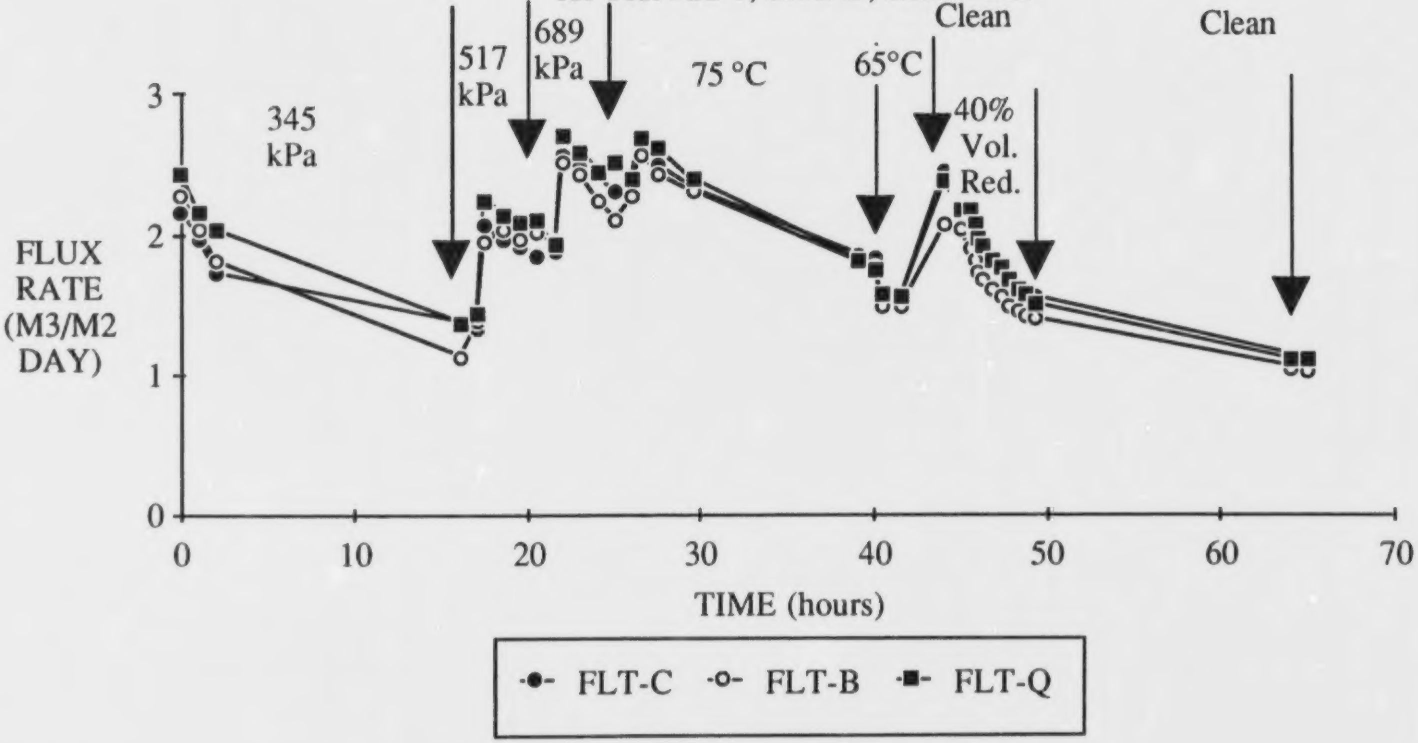


FIGURE 3 - 29

FLUX RATE VS TIME
for Test #S2-1, SITE D, Skim Tank

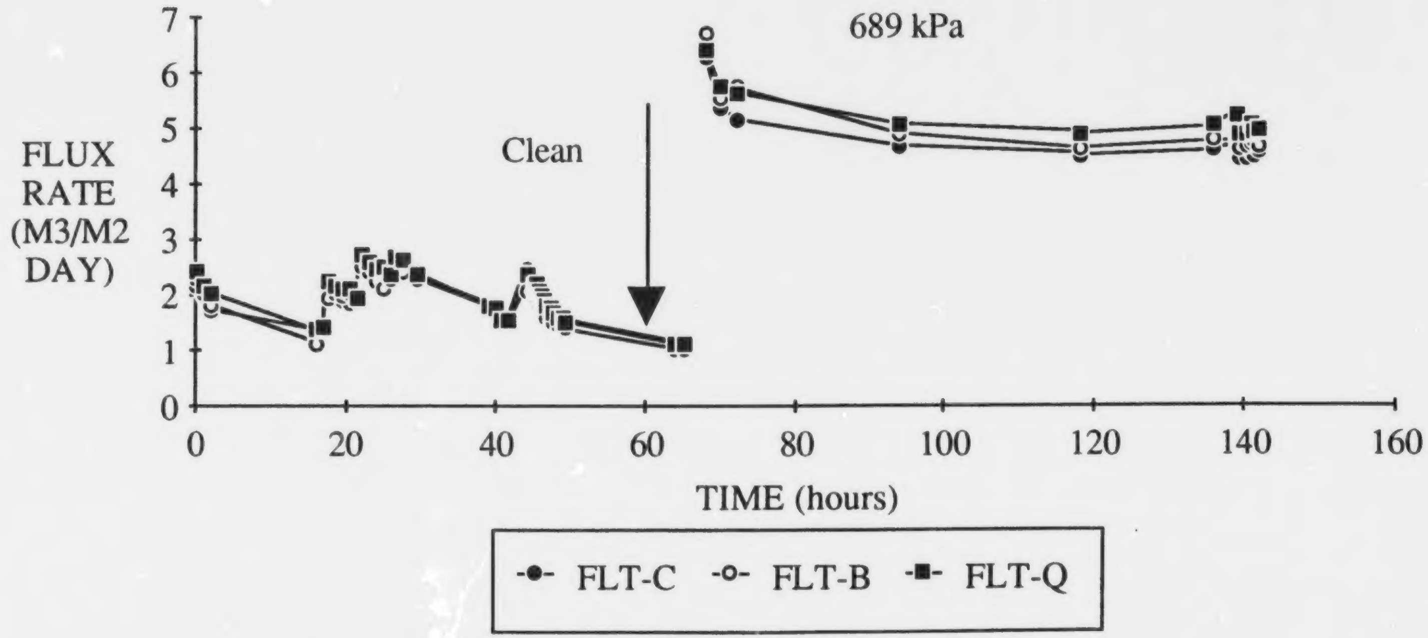


TABLE 3 - 51

PERMEATE QUALITY FOR TEST S2 - 1, SITE D, Skim Tank

DATE: FEBRUARY 3, 1987 MEMBRANES: FLT - C / FLT - B / FLT - Q

PARAMETER	UNITS	TIME = 0 hr.	TIME = 24 hr.	TIME = 141 hr.	
		RAW FEED	PERMEATE FLT - C	40% Vol. Red. CONC.	40% Vol. Red. PERMEATE
pH		7.4	8.3	8.3	8.4
COND.	umho	19.6	18.3	20.7	20.3
TURB.	NTU	16	1.6	900	1.9
COLOUR	APHA	1,100	150	2,500	250
TSO	mg/L	1,290	N/A	N/A	N/A
TDO	mg/L	78	N/A	N/A	N/A
TDS	mg/L	14,000	14,700	16,400	17,100
TSS	mg/L	2,740	N/A	N/A	N/A
CALCIUM	mg/L	300	250	260	260
MAGNESIUM	mg/L	130	110	110	110
HARDNESS	mg/L	1,284	1,077	1,102	1,102
SILICA	mg/L	122	77	8.4	8.8
EXT. OILS	mg/L	25	<10	N/A	N/A
OIL	mg/L	28	N/A	N/A	N/A
SURFACTANT	mg/L	18	12	N/A	N/A

N/A - Not Available

using phosphoric acid to remove inorganics then with MC-40i to remove organic contaminants. After this cleaning there was a dramatic increase in flux rate to 6.3 m^3/m^2/day and the flux stabilized at about 4.5 m^3/m^2/day.

The flux rate during the first half of this run were not stable enough as a result of continued membrane fouling to gather the desired data on the effect of different operating pressures and temperatures. The improvement in flux after cleaning with phosphoric acid suggest very strongly that the material fouling the membrane was inorganic in nature. It is believed that this material fouled the membrane and was removed from the system in the phosphoric acid wash water. The flux rates after cleaning were high and stable because there was little or no remaining fouling compound. Previous samples from this site had very high levels of dissolved solids and hardness but showed no signs of membrane fouling. This sample did contain a higher level of suspended solids (2740 mg/l) than the sample tested previously which contained 580 mg/l. It is believed that these suspended solids caused the fouling problems. Analytical results for this test are shown in Table 3-51. The quality of the permeate as measured by colour and turbidity is good and as before little removal of dissolved inorganic components is observed.

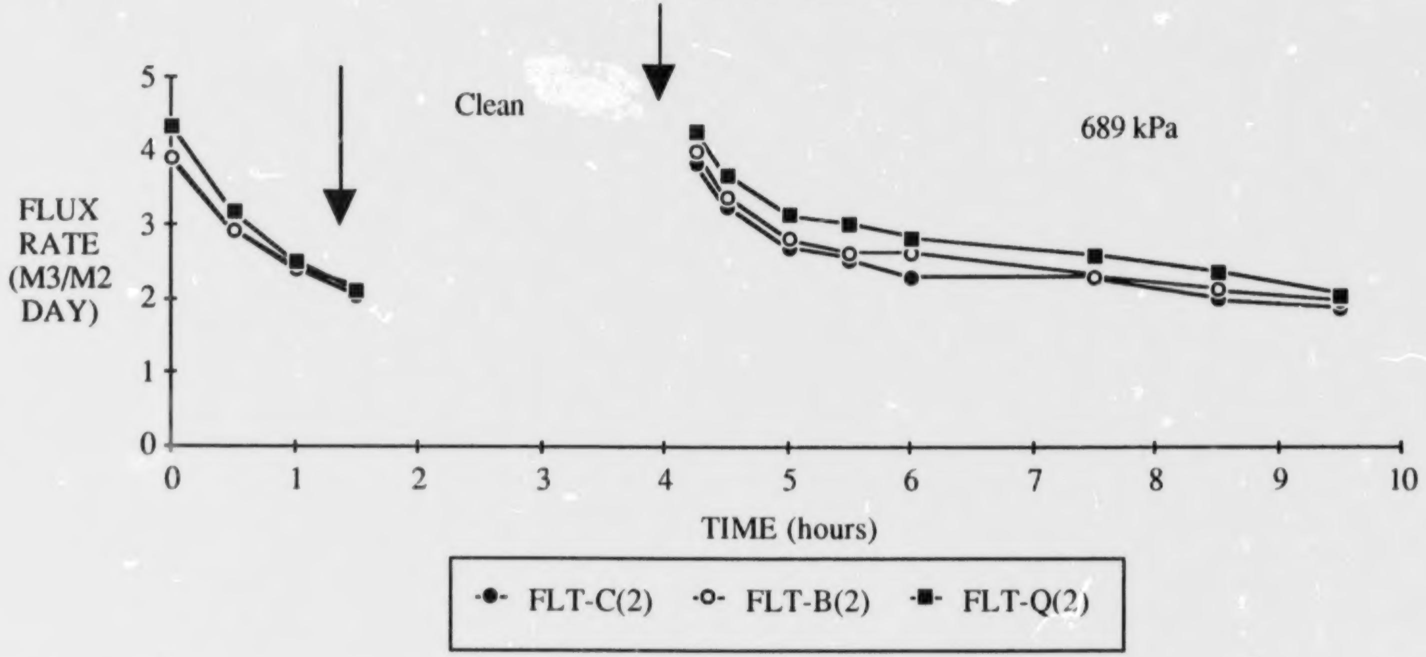
3.8.2 Test #S2-2, Site "D", FWKO

This test was conducted using the same sample of produced water as was used in the previous test. The operating conditions were 100 psi and 65°C as had been used in part of the previous test.

The initial flux rate as shown in Figure 3-30 was 3.8

FIGURE 3 - 30

FLUX RATE VS TIME
for Test #S2-2, SITE D, Skim Tank



m^3/m^2/day but declined to 2.0 m^3/m^2/day during the first 1.5 hr of the test. The system was cleaned with phosphoric acid and MC-40i and the flux went back up to 3.8 m^3/m^2/day then decreased steadily for the remaining 5 hours of the run down to 2.0 m^3/m^2/day.

These results support the suggestion from the first run that inorganic fouling was causing the decrease in flux for this sample of produced water.

3.8.3 Test S2-3 Site "E", FWKO & HTS

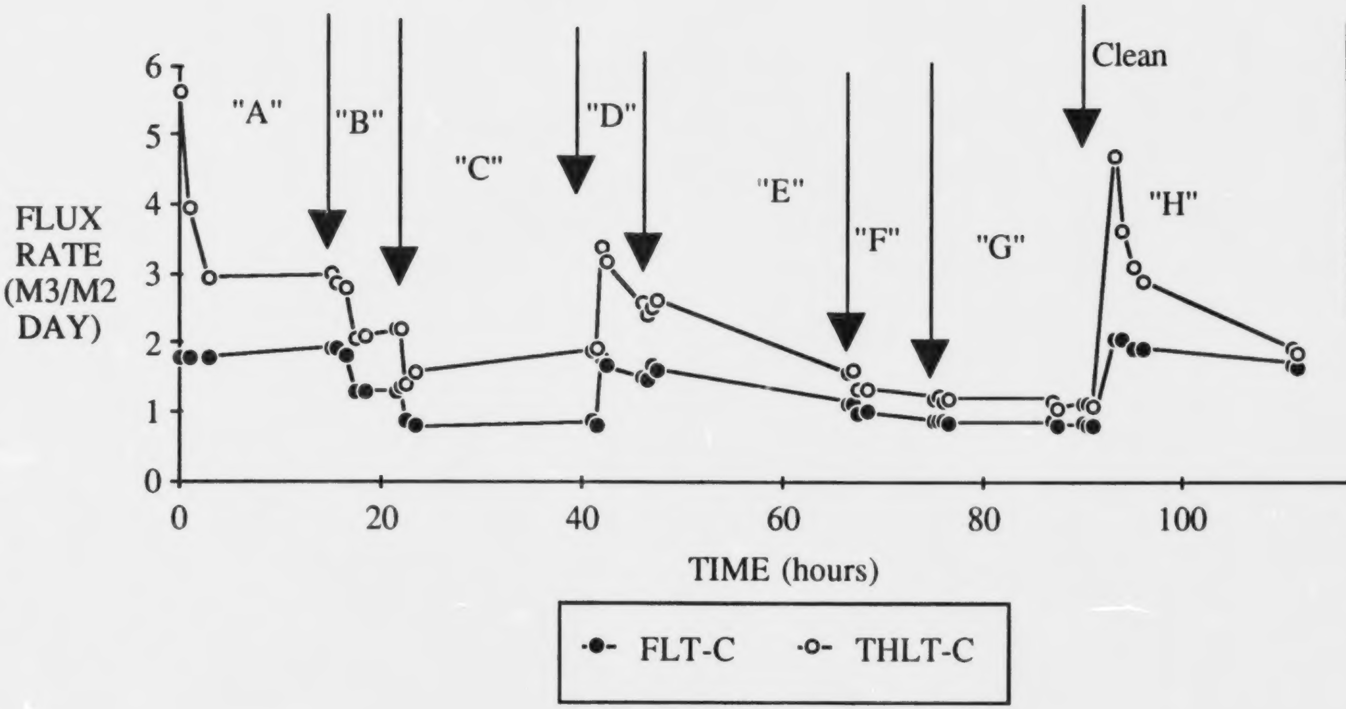
The sample used for this test was obtained from the combined flow from the FWKO & HTS in the produced water treatment process at site "E". Previous tests with samples from this site showed consistently low flux rates only slightly above 1.0 m^3/m^2/day. This sample was brown in colour and contained some suspended solids.

Three membranes with a wide range of pore sizes were used during this test. The standard FLT-C membrane which was tested previously was used along with a looser THLT-C membrane and a tighter FLT-B1. The tight FLT-B1 membrane produced almost no flux during the salt water flux test or produced water testing demonstrating the membrane is too tight to be operated at the low pressures used in this work. The flux for the THLT-C membrane which has a larger molecular weight cut off was consistently higher than for the standard FLT-C membrane. No concentration of the feed was attempted during this test to better evaluate the effect of the other factors of pressure and temperature.

Initially the flux rates as shown in Figure 3-31 for the FLT-C on THLT-C at an operating pressure of 690 kPa (100 psi) were 1.8

FIGURE 3 - 31

FLUX RATE VS TIME
for Test #S2-3, SITE E, FWKO & HTS



	P. kPa	T. °C	Q L/min.
A	689	65	20
B	517	65	20
C	345	65	20
D	689	65	20
E	689	75	20
F	689	65	20
G	689	65	25
H	689	65	20

TABLE 3 - 52

PERMEATE QUALITY FOR TEST S2 - 3, SITE E, FWKO & HTS

DATE: FEBRUARY 12, 1987

MEMBRANES: FLT - C / FLT - B1 / THLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 46 hr.		TIME = 111.5 hr.		
		RAW FEED	PERMEATE FLT - C	PERMEATE THLT - C	FEED	PERMEATE FLT - C	PERMEATE THLT - C
pH		7.35	8.78	8.80	8.94	8.91	8.92
COND.	umho	7.11	5.54	6.12	6.48	5.32	5.93
TURB.	NTU	70	4.5	0.9	360	2.6	1.2
COLOUR	APHA	7,500	275	275	10,000	275	300
TSO	mg/L	490	55	2	N/A	N/A	N/A
TDO	mg/L	330	130	270	N/A	N/A	N/A
TDS	mg/L	6,200	4,450	5,500	N/A	N/A	N/A
TSS	mg/L	540	70	11	N/A	N/A	N/A
CALCIUM	mg/L	32	15	20	N/A	N/A	N/A
MAGNESIUM	mg/L	4.1	1.1	1.3	N/A	N/A	N/A
HARDNESS	mg/L	97	42	55	N/A	N/A	N/A
SILICA	mg/L	195	124	135	N/A	N/A	N/A
EXT. OILS	mg/L	720	<10	<10	N/A	N/A	N/A
OIL	mg/L	640	3.2	8	N/A	N/A	N/A
SURFACTANT	mg/L	36	31	33	N/A	N/A	N/A

N/A - Not Available

m^3/m^2/day and 5.6 m^3/m^2/day respectively. The flux for the FLT-C remained stable for the 16.5 hours while the THLT-C flux decreased quickly to 3.0 m^3/m^2/day and remained stable at that level until the operating conditions were changed. The THLT-C membrane has much larger pores than the FLT-C membrane and some plugging of large pores occurred during the first few hours of operation, but after this initial period the flux was stable and higher. The FLT-C membrane has much smaller pores and the flux was lower but stable even during the first few hours of operation.

The trans membrane pressure was decreased from 100 psi to 75 psi and the flux rates immediately decreased to 1.3 m^3/m^2/day and 2.0 m^3/m^2/day. The FLT-C membrane flux remained stable for 4 1/2 hours under these conditions while the flux for the THLT-C increased gradually to 2.2 m^3/m^2/day.

The pressure was then decreased to 50 psi and the flux rates dropped to 0.9 m^3/m^2/day and 1.4 m^3/m^2/day. Again, the FLT-C flux was stable and the THLT-C flux gradually rose to 1.95 m^3/m^2/day over 19 hours at these operating conditions.

The system was then cleaned and operated at 100 psi and 65°C for 4.5 hours. The flux for the FLT-C membrane increased to where it had been originally at 1.8 m^3/m^2/day and decreased only slightly to 1.5 m^3/m^2/day. The flux for the THLT-C membrane increased after cleaning to 3.4 m^3/m^2/day then decreased to 2.43 m^3/m^2/day. The temperature of the system was then increased to 75°C and the flux rates increased to 1.68 and 2.52 m^3/m^2/day. The flux rates for both membranes decreased by the end of the 20 hours of operation at 75°C. Flux rates were only taken at the start and end of operation at 75°C but it is likely that the flux stabilized at its final level prior to the end of this segment.

The system temperature was decreased back to 65°C and a slight drop in flux was observed. The flux was relatively stable for the following 23.5 hr even during a 15 hour period of time when the flow through membrane test module was increased from 20 L/min to 25 L/min.

The system was cleaned one final time and as before, the flux rates for both membranes increased back up to their original levels then declined down to 1.66 m^3/m^2/day for the FLT-C and 1.88 m^3/m^2/day for the THLT-C.

The flux results from this test demonstrated that the membrane THLT-C is able to obtain a considerably (60%) higher flux than the previously used FLT-C membrane. The results showing gradual improvement in flux with time at lower pressures for the THLT-C membrane suggest that some membrane compression may be occurring with this membrane at the higher pressure of 689 kPa (100 psi). The structure and composition of the THLT-C membrane are such that operation at high transmembrane pressures can cause the membrane to compact and reduce the permeability of the membrane. As the transmembrane pressure is reduced the membranes may relax and the porosity and flux may increase.

Operation of the system at 75°C resulted in only a slight increase in flux which was not sustained during the following period of time. The flux rate was not affected by a change in the flow to the membrane module.

The flux rates during the latter half of the test were lower than were observed initially in the test as a result of some membrane fouling which appeared to increase as the sample aged. The results do demonstrate however, that the cleaning of the membranes is effective in removing the fouling material and restoring flux. Analytical data for this test are shown in Table 3-52. Permeate quality is comparable to that obtained during previous tests.

3.8.4 Test S2-4 Site "E", FWKO & HTS pH 9.0

The sample used for this test was the same as was used in the previous test S2-3 except that the pH of the produced water was adjusted with NaOH from 7.5 to a level of 9.0. The same three types of membrane used in the previous test were also used for this experiment.

The operating conditions for this test were initially 65°C and a trans membrane pressure of 689 kPa (100 psi). The pressure was decreased to 517 kPa (75 psi) then to 345 kPa (50 psi) in two steps while keeping the temperature at 65°C. All permeate was recycled to the process tank until the 120 hour mark when the feed was concentrated to a 61.4% volume reduction (CF = 2.6).

The initial flux rate for the FLT-C membrane as shows in Figure 3-32 was 1.65 m^3/m^2/day and remained steady at that level for the 26.5 hr of operation at a pressure of 689 kPa (100 psi). Flux for the THLT-C membrane started above 6 m^3/m^2/day then decreased to 3.5 m^3/m^2/day where it remained for the 26.5 hr of operation at 100 psi.

When operating pressure was decreased to 75 psi and the flux for the FLT-C and THLT-C membranes decreased to 1.26 and 2.7 m^3/m^2/day. The flux for the FLT-C remained stable for 19 hours at

FIGURE 3 - 32

FLUX RATE VS TIME
for Test #S2-4, SITE E, FWKO & HTS, pH 9.0

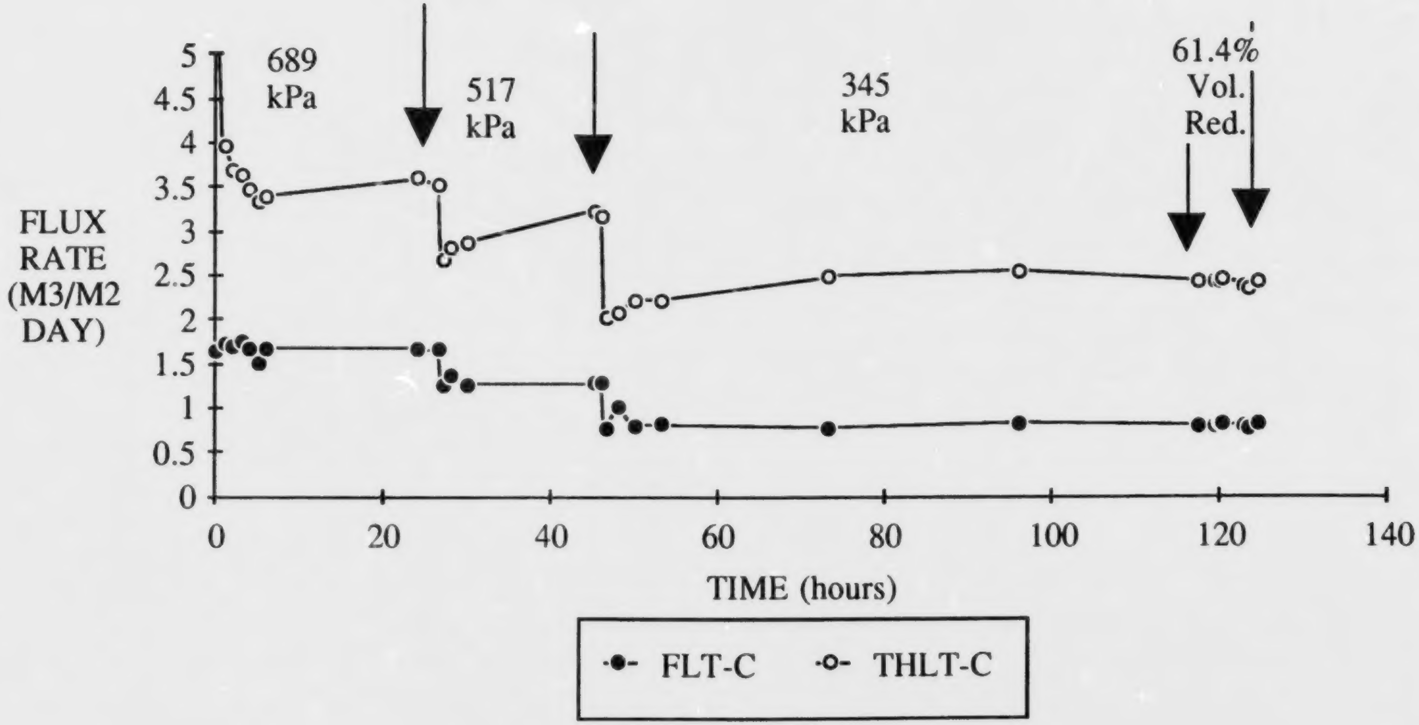


TABLE 3 - 53

PERMEATE QUALITY FOR TEST S2 - 4, SITE E, FWKO & HTS, pH 9.0

DATE: FEBRUARY 17, 1987

MEMBRANES: FLT - C / FLT - B1 / THLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 26.5 hr.			TIME = 120 TO 123.5 hr. 61.4 % Vol. Red.			TIME = 123.5 hr. 61.4 % Vol. Red.
		RAW FEED	FEED pH 9.0	PERMEATE FLT - C	PERMEATE THLT - C	COMPOSITE PERMEATE FLT-C	COMPOSITE PERMEATE FLT - B1	COMPOSITE PERMEATE THLT - C	CONCENTRATE
pH		7.4	8.9	8.7	8.8	9.0	8.8	9.0	9.0
COND.	umho	7.1	6.8	5.5	6.0	5.0	5.2	5.7	6.6
TURB.	NTU	70	340	3.2	2.3	3	5.7	2.7	43
COLOUR	APHA	7,500	7,500	90	180	140	65	350	22,500
TSO	mg/L	490	560	N/A	N/A	51	N/A	36	N/A
TDO	mg/L	330	420	N/A	N/A	230	N/A	290	N/A
TDS	mg/L	6,200	N/A	N/A	N/A	3,850	N/A	4530	N/A
TSS	mg/L	540	590	N/A	N/A	39	N/A	24	N/A
CALCIUM	mg/L	32	29	N/A	N/A	22	N/A	24	N/A
MAGNESIUM	mg/L	4.1	1.1	N/A	N/A	1.3	N/A	0.52	N/A
HARDNESS	mg/L	97	77	N/A	N/A	60	N/A	62	N/A
SILICA	mg/L	195	161	N/A	N/A	107	N/A	122	N/A
EXT. OILS	mg/L	720	780	N/A	N/A	12	N/A	13	N/A
OIL	mg/L	640	416	N/A	N/A	7.8	N/A	8.6	N/A
SURFACTANT	mg/L	36	30	N/A	N/A	16	N/A	24	N/A

N/A - Not Available

this operating condition while the flux for the THLT-C membrane increased to 3.2 m^3/m^2/day.

The operating pressure was further decreased to 50 psi and the flux for the FLT-C and THLT-C membranes decreased to 0.78 and 2.0 m^3/m^2/day. Again the flux for the FLT-C was stable for the remaining 73 hours at this operating condition while the flux for the THLT-C membranes increased to 2.4 m^3/m^2/day.

After 120 hr of operation in a recycle mode, the permeate was diverted from recycle and the produced water was concentrated over 3.5 hr to a volume reduction of 61.4% (CF of 2.6). During this concentration, there was no change in flux rate for either membrane.

The results of this test demonstrate that for the THLT-C membrane, a significant (20%) increase in flux can be obtained by increasing the pH of the produced water. There was no apparent effect of pH on the flux with the FLT-C membrane tested. The results also demonstrated that the flux for THLT-C membrane does not decrease in direct proportion to a decrease in trans membrane pressure. This is believed to be a result of some membrane compression at higher pressures. The relatively high flux obtained at only 50 psi of 2.4 m^3/m^2/day may be of interest since system operating costs may be reduced by operating at lower pressures. Reductions in membrane modules and pumping costs may be significant if the operating pressure is reduced from 100 to 50 psi.

The results from the final few hours of the test demonstrates that the flux rate does not decrease during concentration of the produced water emulsion. Analytical data for the run is shown in Table 3-53.

3.8.5 Test S3-1, Site "E", FWKO & HTS, pH 9.0

The sample used for this test was the same as was used in the previous two tests S2-3 and S2-4 and as in test S2-4, the pH of the produced water was adjusted from about 7.5 to 9.0 with NaOH. The membranes used were the same actual membranes as were used in the previous S2-4 test. This test was conducted to simulate a second concentration cycle using a fresh sample of produced water.

Initially, the system was operated at 65°C with a trans membrane pressure of 345 kPa (50 psi). The flux for the FLT-C(2) (the (2) indicates that the actual membrane is being used for the second time) and THLT-C (2) membranes as shown in Figure 3-33 were initially 0.9 m^3/m^2/day and 3.6 m^3/m^2/day.

The system was operated overnight and it was found that the temperature of the system had increased to 95°C as a result of a leak in a cooling water line. The temperature was returned back to 65°C and the flux rates were measured at 1.63 m^3/m^2/day and 3.64 m^3/m^2/day. At the 17.5 hour mark, concentration of the produced water was begun. Over the following 6.25 hours the sample was concentrated to a 42.6% volume reduction and the flux rates for the FLT-C and THLT-C membranes declined to 1.32 and 2.85 m^3/m^2/day. At this point in time, a problem was encountered with the pump and the system was shut down for two days. After the pump was reinstalled, the membranes were cleaned and the produced water was further concentrated to a 60% volume reduction over the following 4.75 hours. The flux rates at this time were 1.22 and 2.49 m^3/m^2/day. The system was then left overnight with no volume reduction. The flux rates declined slightly to 1.04 and 1.88 m^3/m^2/day. The produced water was further concentrated to an 87% volume

FIGURE 3 - 33

FLUX RATE VS TIME
for Test #S3-1, SITE E, FWKO & HTS, pH 9.0

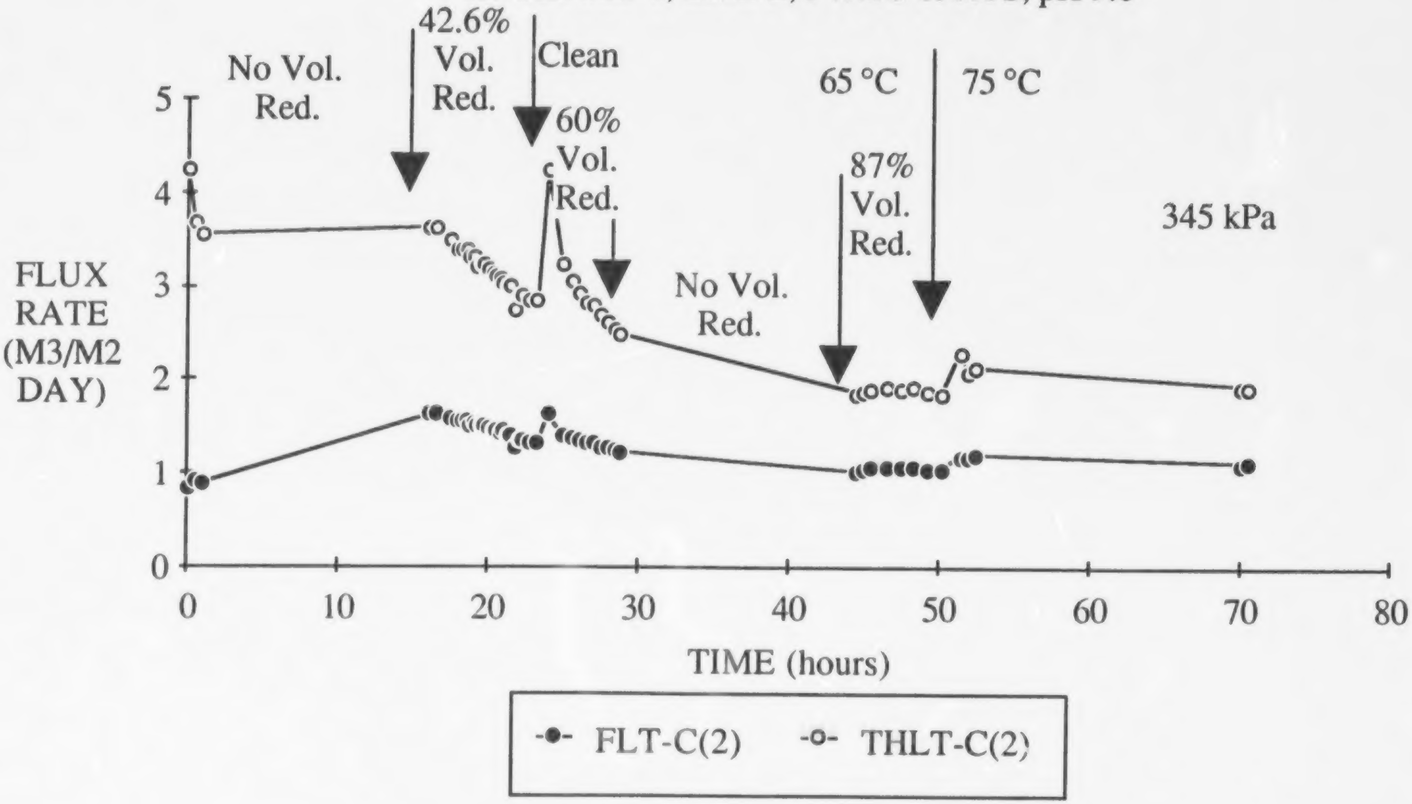


TABLE 3 - 54

PERMEATE QUALITY FOR TEST S3 - 1, SITE E, FWKO & HTS, pH 9.0

DATE: FEBRUARY 23, 1987 MEMBRANES: FLT - C(2) / FLT - B1(2) / THLT - C(2)

PARAMETER	UNITS	TIME = 0 hr.		TIME = 0 TO 50.25 hr.			TIME = 123.5 hr.
		RAW FEED	FEED pH 9.0	COMPOSITE PERMEATE FLT-C(2)	COMPOSITE PERMEATE FLT - B1(2)	COMPOSITE PERMEATE THLT - C(2)	87 % Vol. Red. CONCENTRATE
pH		7.4	8.9	8.8	8.8	8.8	9.2
COND.	umho	7.1	6.8	6.9	6.5	7.0	7.9
TURB.	NTU	70	340	5	5.0	4	14
COLOUR	APHA	7,500	7,500	75	50	100	50,000
TSO	mg/L	490	560	63	45	45	N/A
TDO	mg/L	330	420	350	380	320	N/A
TDS	mg/L	6,200	N/A	5,500	5,560	5,140	N/A
TSS	mg/L	540	590	42	46	45	N/A
CALCIUM	mg/L	32	29	25	21	26	N/A
MAGNESIUM	mg/L	4.1	1.1	0.75	0.58	0.77	N/A
HARDNESS	mg/L	97	77	66	55	68	N/A
SILICA	mg/L	195	161	182	176	180	N/A
EXT. OILS	mg/L	720	780	11	<10	<10	N/A
OIL	mg/L	640	416	12.4	4.4	9.8	N/A
SURFACTANT	mg/L	36	30	27	24	28	N/A

N/A - Not Available

reduction (CF = 7.7) between 45.5 hours and 50.25 hours. The flux rates remained stable during this final concentration.

Immediately following this concentration, the temperature of the system was increased from 65°C to 75°C and the flux rates increased to 1.18 and 2.28 m^3/m^2/day. Overnight at this temperature, the flux remained relatively stable but had declined to 1.12 and 1.92 m^3/m^2/day for the FLT-C(2) and THLT-C(2) membranes. Analytical data for this test is shown in Table 3-54.

3.8.6 Test S3-2, Site "E", FWKO & HTS

The sample used for this test was the same as was used in the previous three tests #S2-3, S2-4, and S3-1 but the pH of the produced water was not adjusted.

The membranes used were the same actual FLT-C(3) and THLT-C(3) membranes used in Test S3-1 and a new THLT-C1 membrane. This test was conducted to simulate a third concentration cycle and obtain data from operation at 75°C and 85°C.

Initially, the system was operated at 65°C with a trans membrane pressure of 345 kPa (50 psi). The flux for the FLT-C(3), THLT-C1, and THLT-C(3) membranes as shown in Figure 3-34 were 0.92, 6.38, and 3.54 m^3m^2/day. During 9 hours of concentration to a volume reduction of 84.1% (CF of 6.3) the rates for the FLT-C(3) did not change at all while the flux rates for the THLT-C1 and THLT-C both declined to almost the same levels of 2.2 and 2.1 m^3/m^2/day. During 15 hours of operation in a recycle mode at 65°C, the flux rates for all three membranes were stable at 0.8, 1.9, and 1.9 m^3/m^2/day for the FLT-C, THLT-C1, and THLT-C(3) membranes. At the 25 hour mark, the

FIGURE 3 - 34

FLUX RATE VS TIME
for Test #S3-2, SITE E, FWKO & HTS

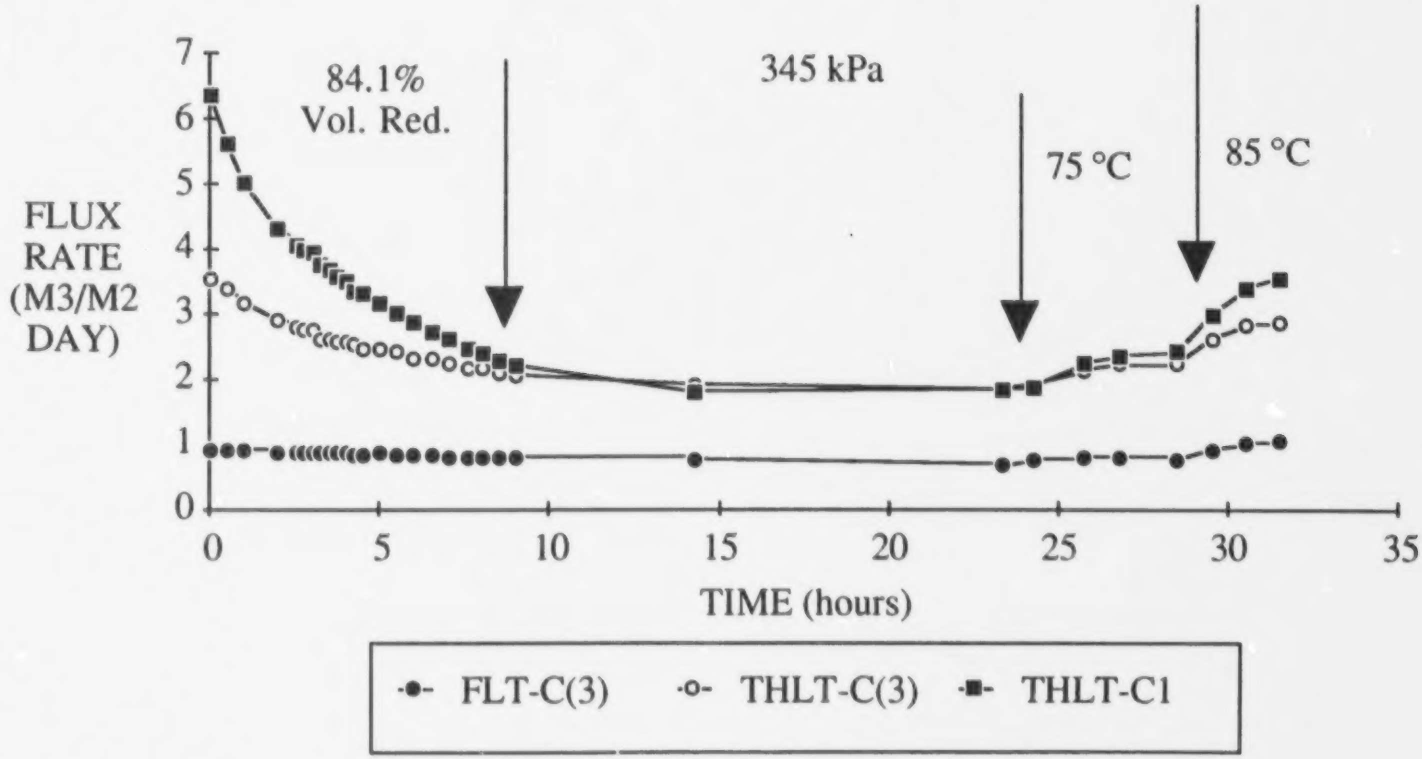


TABLE 3 - 55

PERMEATE QUALITY FOR TEST S3 - 2, SITE E, FWKO & HTS

DATE: MARCH 4, 1987

MEMBRANES: FLT - C(3) / THLT - C(3) / THLT - C1

PARAMETER	UNITS	TIME = 0 hr.	TIME = 2.5 TO 9.0 hr. 84.13% Vol. Red.			TIME = 31.5 hr. 84.13 % Vol. Red.
		RAW FEED	PERMEATE FLT - C(3)	PERMEATE THLT - C(3)	PERMEATE THLT - C1	CONCENTRATE
pH		7.4	8.1	8.2	8.2	8.7
COND.	umho	7.1	6.6	6.5	6.4	7.6
TURB.	NTU	70	4.6	3.4	4.7	13
COLOUR	APHA	7,500	375	425	425	22,500
TSO	mg/L	490	39	51.5	49	N/A
TDO	mg/L	330	280	290	260	N/A
TDS	mg/L	6,200	5,160	5,300	5,190	N/A
TSS	mg/L	540	42	47	48	N/A
CALCIUM	mg/L	32	27	27	28	N/A
MAGNESIUM	mg/L	4.1	3.5	3.5	3.2	N/A
HARDNESS	mg/L	97	82	82	83	N/A
SILICA	mg/L	195	176	180	176	N/A
EXT. OILS	mg/L	720	<10	<10	11	N/A
OIL	mg/L	640	8.4	15	4.8	N/A
SURFACTANT	mg/L	36	32	33	30	N/A

N/A - Not Available

temperature was increased to 75°C and the flux for the FLT-C(3) membrane increased only very slightly to 0.81 m^3/m^2/day. The flux for the THLT-Cl increased to 2.25 m^3/m^2/day and continued to increased during 3 hours of operation at this temperature up to 2.43 m^3/m^2/day. The flux for the THLT-C(3) increased from 1.92 to 2.25 m^3/m^2/day during 3 hours of operation at 75°C.

At the 29 hour mark, the system temperature was increased to 85°C and the flux for the FLT-C(3) membrane increased slightly to 0.93 m^3/m^2/day then to 1.07 m^3/m^2/day after an additional 2 hours. The flux rate for the THLT-Cl membrane increased to 3.00 m^3/m^2/day and continued to increase to 3.54 m^3/m^2/day during 2 hours of operation at 85°C. The flux for the THLT-C(3) membrane increased to 2.64 m^3/m^2/day and continued to increase to 2.88 m^3/m^2/day during 2 hours of operation at 85°C.

The quality of the permeate as measured by colour did not change significantly for any of the membranes as the temperature was increased. Analytical data for this test is presented in Table 3-55.

3.8.7 Test S3-3, Site "C ", Skim Tank

The sample used for this test was obtained from the skim tank at EOR Site "C". The membranes used were FLT-C, THLT-C, and a new formulation, HLT-SC.

This run was conducted with no concentration of the feed to examine the performance of the membranes with this sample of produced water and the effect of increasing the operating temperature of the system. The pressure was maintained at 345 kPa (50 psi) throughout the test.

The flux for the FLT-C at the start of the run, as shown in Figure 3-35, was 1.5 m^3/m^2/day and the flux remained stable for the 6 hours of operation at 65°C. The flux for the THLT-C was initially 3.0 m^3/m^2/day but stabilized at 1.5 m^3/m^2/day after 3 hours of operation. The flux for the HLT-SC membrane was considerably higher than the other membranes (5.94 m^3/m^2/day initially) and declined slowly during 6 hours of operation at 65°C to 2.46 m^3/m^2/day.

After 6 hours of operation, the temperature was increased to 75°C and the flux for the FLT-C, THLT-C, and HLT-SC membranes increased to 1.9, 1.7, and 2.75 m^3/m^2/day.

After one hour at 75°C, the temperature was increased further to 85°C and the flux for the FLT-C membrane increased to 2.6 m^3/m^2/day and continued to increase to 3.0 m^3/m^2/day. The flux for the THLT-C and HLT-SC membranes increased to 2.16 and 3.3 m^3/m^2/day respectively. Analytical data for this run are shown in Table 3-56.

3.8.8 Test S3-4, Site "C", Skim Tank, pH 9.0

The sample used for this test was the same as was used in Test S3-3 but the pH of the sample was adjusted to 9.0 with NaOH. The membranes used in this were again the FLT-C, THLT-C, and HLT-SC membranes.

This run was conducted again with no concentration of the feed to examine membrane performance with the pH adjusted sample and determine the effect of operating pressure, flow through the membrane module, and temperature.

The flux rates obtained during this experiment at a variety of operating conditions are shown in Figure 3-36. All three membranes

FIGURE 3 - 35

FLUX RATE VS TIME
for Test #S3-3, SITE C, Skim Tank

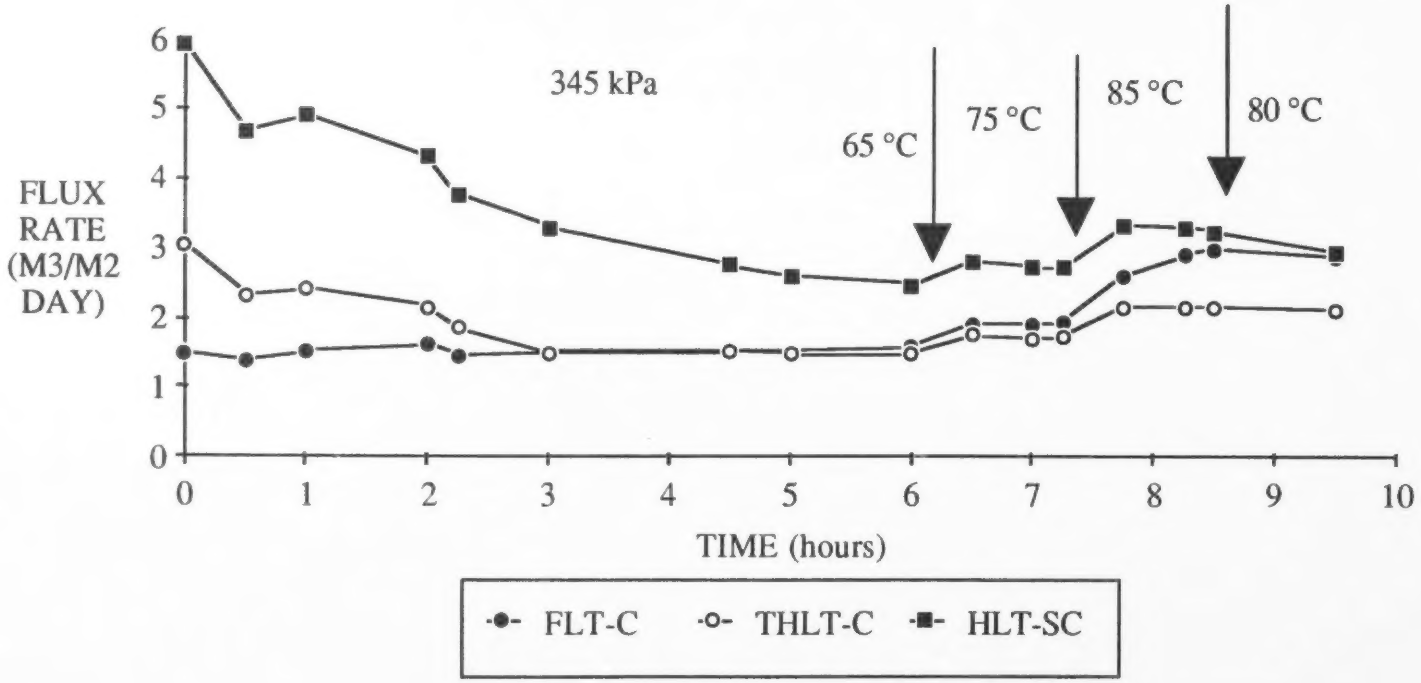


TABLE 3 - 56

PERMEATE QUALITY FOR TEST S3 - 3, SITE C, Skim Tank

DATE: MARCH 22, 1987 MEMBRANES: THLT - C / HLT - SC / FLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 6.0 hrs.		
		RAW FEED	PERMEATE THLT - C	PERMEATE HLT - SC	PERMEATE FLT - C
pH		7.2	7.9	7.5	8.1
COND.	umho	12.2	11.2	11.4	11.4
TURB.	NTU	82	5.5	17	10
COLOUR	APHA	1,750	200	225	175
TSO	mg/L	120	N/A	N/A	N/A
TDO	mg/L	430	N/A	N/A	N/A
TDS	mg/L	9,530	N/A	N/A	N/A
TSS	mg/L	68	N/A	N/A	N/A
CALCIUM	mg/L	94	N/A	N/A	N/A
MAGNESIUM	mg/L	5.4	N/A	N/A	N/A
HARDNESS	mg/L	257	N/A	N/A	N/A
SILICA	mg/L	137	N/A	N/A	N/A
EXT. OILS	mg/L	26	N/A	N/A	N/A
OIL	mg/L	25	N/A	N/A	N/A
SURFACTANT	mg/L	35	N/A	N/A	N/A

N/A - Not Available

FIGURE 3 - 36

FLUX RATE VS TIME
for Test #S3-4, SITE C, Skim Tank, pH 9.0

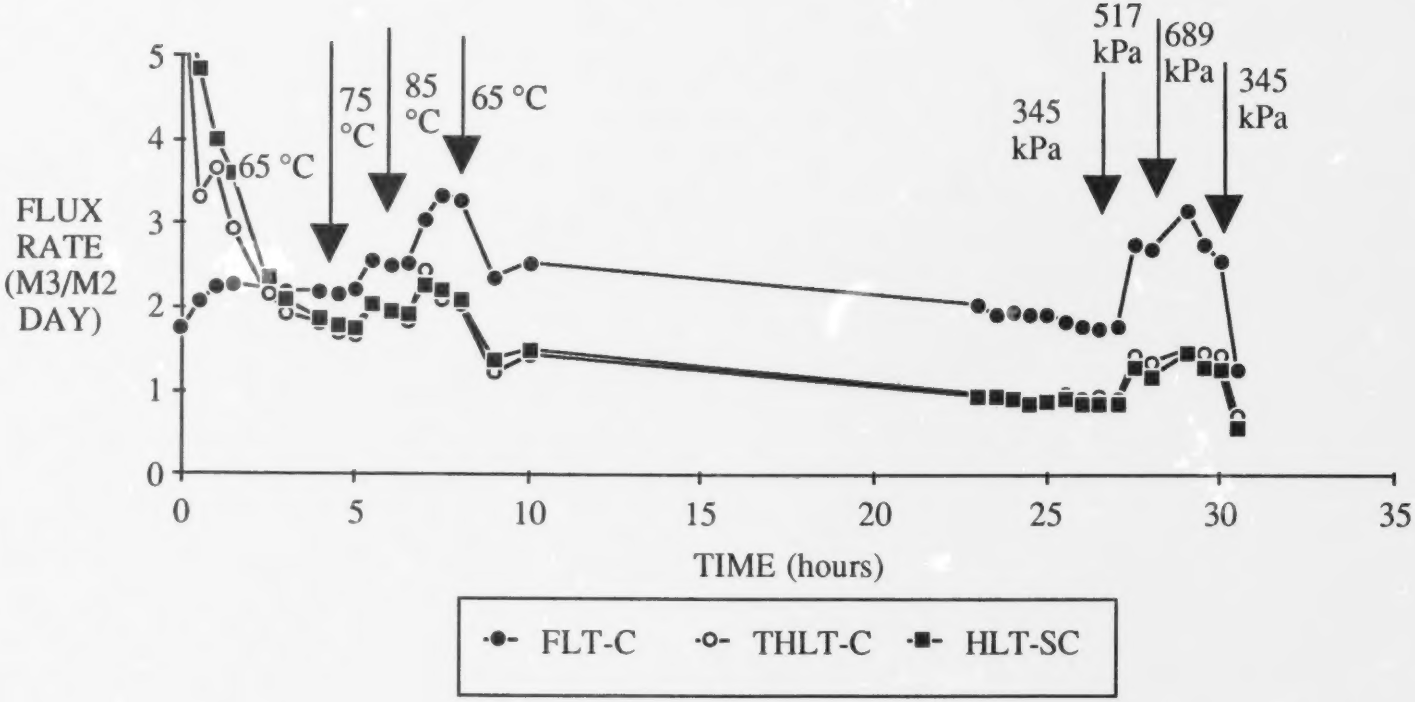


TABLE 3 - 57

PERMEATE QUALITY FOR TEST S3 - 4, SITE C, Skim Tank, pH 9.0

DATE: MARCH 25, 1987

MEMBRANES: HLT - SC / FLT - C / THLT - C

PARAMETER	UNITS	TIME = 0 hr.		TIME = 4.5 hrs.		
		RAW FEED	RAW FEED pH. 9.0	PERMEATE HLT - SC	PERMEATE FLT - C	PERMEATE THLT - C
pH		7.2	8.6	8.6	8.6	8.7
COND.	umho	12.2	11.4	11.3	10.9	11.3
TURB.	NTU	82	68	6.5	3.5	4.0
COLOUR	APHA	1,750	2,500	300	125	275
TSO	mg/L	120	72	N/A	N/A	N/A
TDO	mg/L	430	440	N/A	N/A	N/A
TDS	mg/L	9,530	9,380	N/A	N/A	N/A
TSS	mg/L	68	85	N/A	N/A	N/A
CALCIUM	mg/L	94	82	N/A	N/A	N/A
MAGNESIUM	mg/L	5.4	3.8	N/A	N/A	N/A
HARDNESS	mg/L	257	221	N/A	N/A	N/A
SILICA	mg/L	137	190	N/A	N/A	N/A
EXT. OILS	mg/L	26	22	N/A	N/A	N/A
OIL	mg/L	25	14	N/A	N/A	N/A
SURFACTANT	mg/L	35	21	N/A	N/A	N/A

N/A - Not Available

obtained flux rates near 2.0 m^3/m^2/day in the first few hours of operation. As the temperature of the system was increased to 75°C, then to 85°C, the flux rates for all membranes increased but the flux for the FLT-C increased much more than for the other membranes to well over 3.0 m^3/m^2/day. The flux for all membranes decreased significantly when the operating temperature was returned to 65°C but the flux for the FLT-C remained significantly higher than for the other two membranes.

The flux for all membranes increased when the operating pressure was increased from 345 kPa (50 psi) to 689 kPa (100 psi) but after it was decreased back to 345 kPa (50 psi) the flux rates were much lower than they had been previously during operation at 345 kPa. Operation at higher pressures may result in a decrease in flux by compressing the membranes slightly or by causing fouling material to be driven deeper within the membrane itself thereby limiting the flux which can be obtained. Analytical data for this run is shown in Table 3-57.

3.8.9 Test S3-5, Site "C", Skim Tank

The sample used for this test was the same as was used in Test S3-4 but the pH was not adjusted. A new set of the same type of membranes as was used in the previous test was used.

This test was conducted at 345 kPa (50 psi) and 65°C and the sample was concentrated to an 89% volume reduction to similate a batch concentration cycle. The flux rates obtained are shown in Figure 3-37. The flux for the THLT-C and HLT-SC were initially above 3.0 m^3/m^2/day then declined to about 1.5 m^3/m^2/day during concentration. The flux for the FLT-C was initially slightly greater than 1.0

FIGURE 3 - 37

FLUX RATE VS TIME
for Test #S3-5, SITE C, Skim Tank

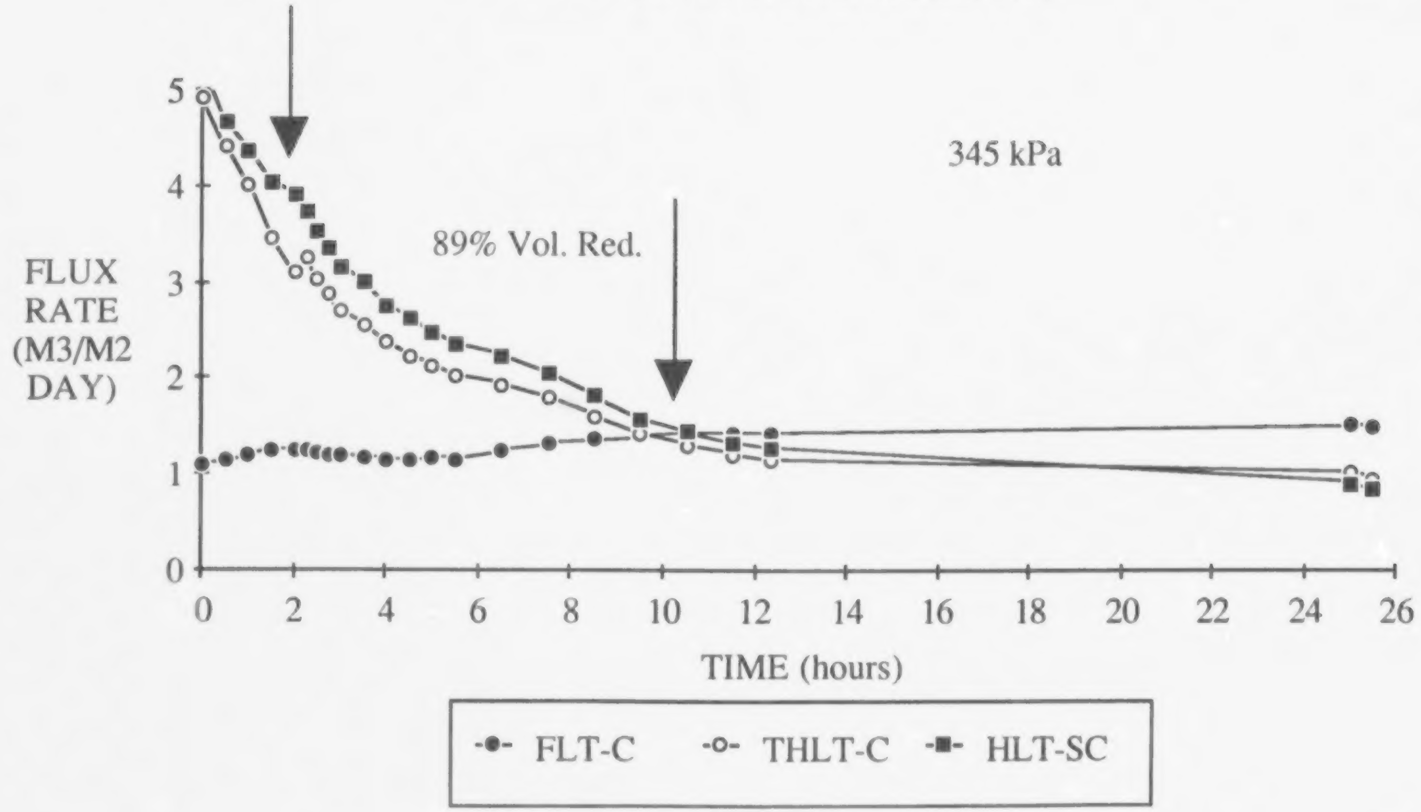


TABLE 3 - 58

PERMEATE QUALITY FOR TEST S3 - 5, SITE C, Skim Tank

DATE: MARCH 28, 1987 MEMBRANES: HLT - SC / FLT - C / THLT - C

PARAMETER	UNITS	TIME = 0 hr.	TIME = 2.25 hrs. to 12.33 hrs.			TIME= 25.5 hrs.
		RAW FEED	PERMEATE THLT - C	PERMEATE FLT - C	PERMEATE HLT - SC	87% Vol. Red. CONC.
pH		17.2	8.0	8.0	8.0	8.4
COND.	umho	12.2	11.8	11.6	11.6	12.9
TURB.	NTU	82.0	2.5	2.7	2.4	1,250
COLOUR	APHA	1,750	500	325	370	17,500
TSO	mg/L	120	36	51	49	410
TDO	mg/L	430	370	400	400	750
TDS	mg/L	9,530	9,290	9,060	9,230	11,400
TSS	mg/L	68	30	27	29	690
CALCIUM	mg/L	94	79	77	79	100
MAGNESIUM	mg/L	5.4	4.4	3.8	4.3	4.3
HARDNESS	mg/L	257	216	208	215	268
SILICA	mg/L	137	173	188	171	122
EXT. OILS	mg/L	26	<10	<10	<10	87
OIL	mg/L	25	7.0	3.0	1.3	23
SURFACTANT	mg/L	35	21	18	17	11

N/A - Not Available

m^3/m^2/day then increased slightly during concentration. In this and the previous test with sample from site "C" the FLT-C membrane has performed better than the larger pore THLT-C membrane which consistently outperformed the FLT-C in tests with sample from site "E". The site "C" water may contain components which are not present in sample from site "E" which are fouling the larger pores of THLT-C membrane. Analytical data showing the quality of the composite permeate collected during concentration is presented in Table 3-58.

3.8.10 Test S3-6, Site "C", Skim Tank

The sample used for this test was the same as was used in the previous 3 tests and the pH was not adjusted. The same actual membrane that were used in Test S3-5 were again used in this test to simulate a second concentration cycle with the membranes. This test was conducted at 345 kPa (50 psi) and 85°C.

The flux rates obtained are shown in Figure 3-38. As in the previous tests, the flux for the THLT-C and HLT-SC membranes were high initially, then decreased during concentration. The flux for the FLT-C was initially much lower but remained more stable during concentration. Analytical data showing the quality of the composite permeate collected during concentration is presented in Table 3-59.

3.8.11 Comparison Of S2 & S3 Tests

Table 3-60 shows a summary of flux rates obtained with the FLT-C and THLT-C membranes for all of the S2 and S3 tests at different operating conditions. Figure 3-39 shows the effect of transmembrane pressure on flux rates for different membranes and feed pH for sample

FIGURE 3 - 38

FLUX RATE VS TIME
for Test #S3-6, SITE C, Skim Tank

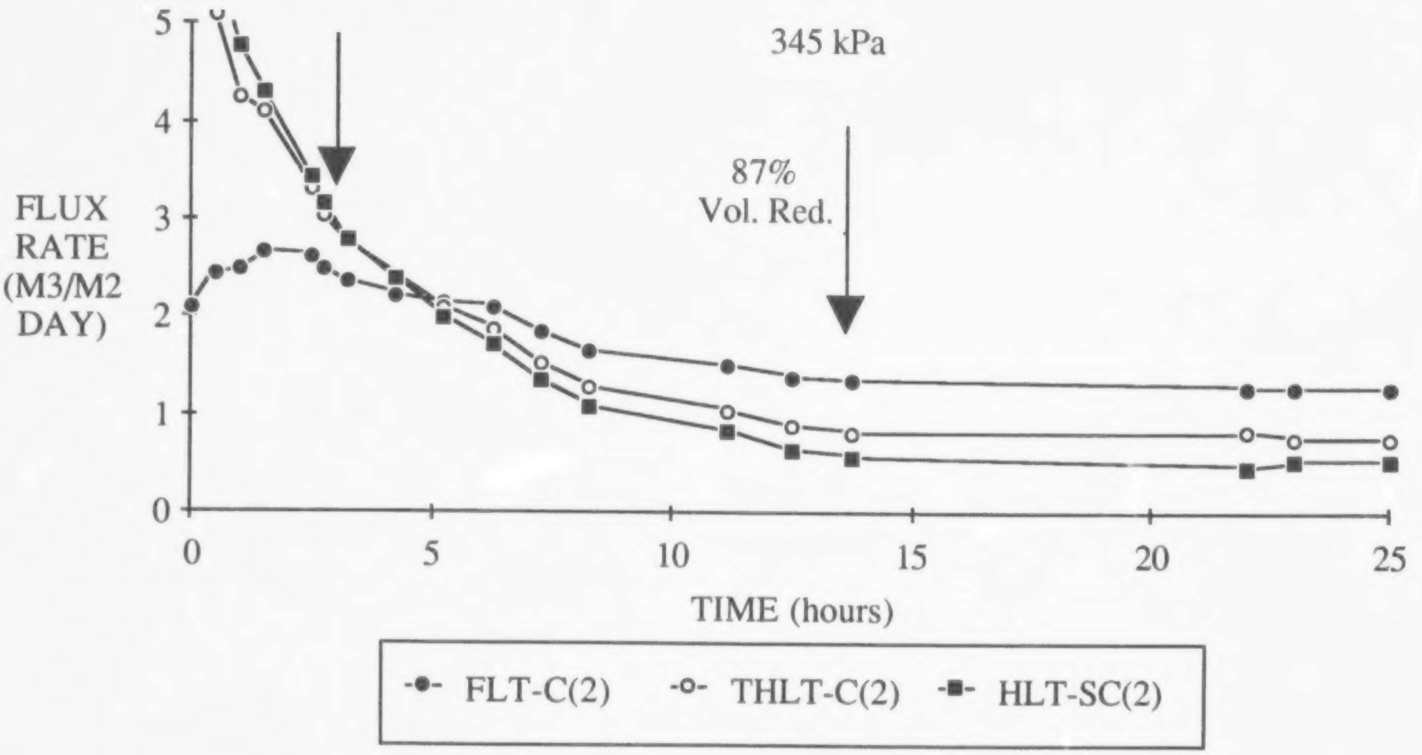


TABLE 3 - 59

PERMEATE QUALITY FOR TEST S3 - 6, SITE C, Skim Tank

DATE: MARCH 29, 1987 MEMBRANES: HLT - SC(2) / FLT - C(2) / THLT - C(2)

PARAMETER	UNITS	TIME = 0 hr.	TIME = 2.5 hrs. TO 13.75 hrs.			TIME= 25.5 hrs.
		RAW FEED	PERMEATE THLT - C(2)	PERMEATE FLT - C(2)	PERMEATE HLT - SC(2)	87% Vol. Red. CONC.
pH		17.2	8.3	8.3	8.2	8.4
COND.	umho	12.2	11.9	12.1	12.1	13.2
TURB.	NTU	82.0	1.7	3.4	1.9	1,350
COLOUR	APHA	1,750	650	550	750	15,000
TSO	mg/L	120	40	73	N/A	N/A
TDO	mg/L	430	360	330	N/A	N/A
TDS	mg/L	9,530	9,400	9,310	9,425	N/A
TSS	mg/L	68	34	8	47	N/A
CALCIUM	mg/L	94	85	86	86	N/A
MAGNESIUM	mg/L	5.4	4.1	4.1	4.2	N/A
HARDNESS	mg/L	257	229	232	232	N/A
SILICA	mg/L	137	205	214	207	N/A
EXT. OILS	mg/L	26	<10	<10	<10	N/A
OIL	mg/L	25	1.0	4.3	5.0	N/A
SURFACTANT	mg/L	35	23	23	17	N/A

N/A - Not Available

TABLE 3 - 60

Summary of Flux Rates for Optimization Testing

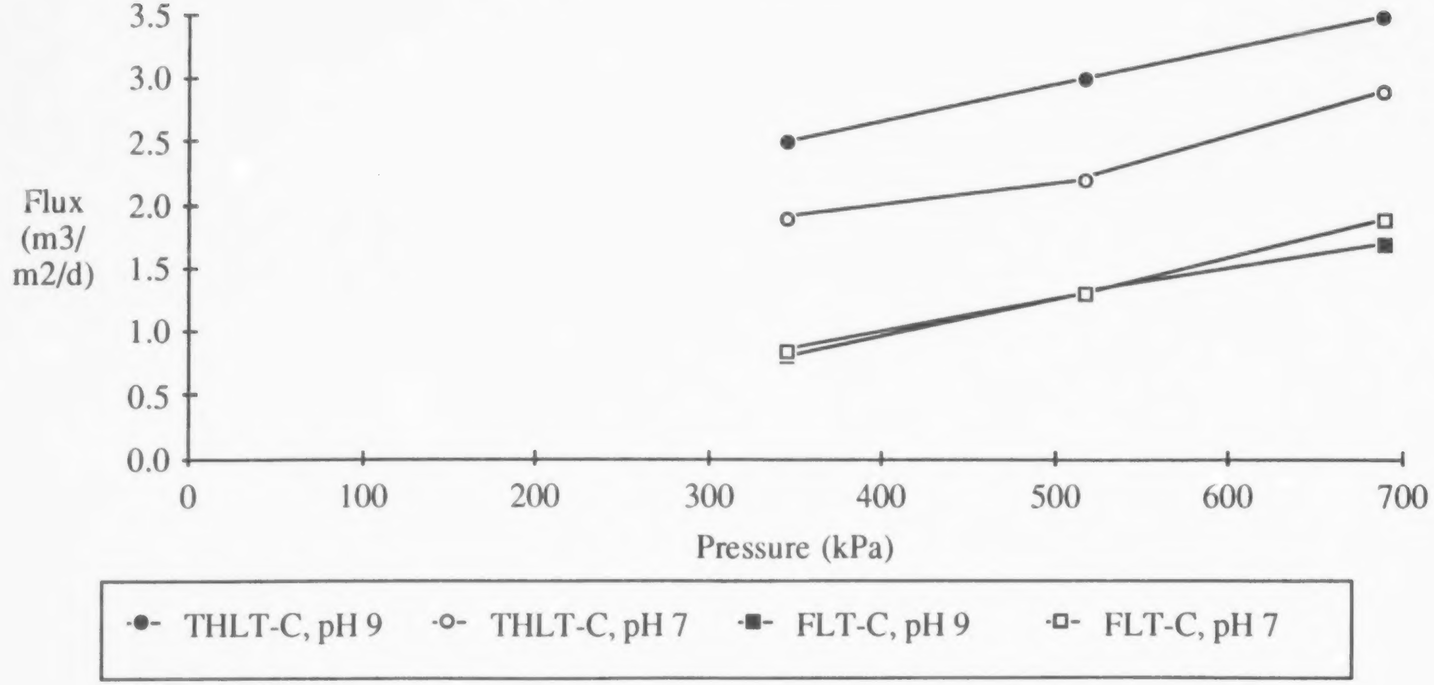
TEST	SITE	pH	Vol.	FLT-C					THLT-C				
			Vol.	690 kPa	517 kPa	345 kPa			690 kPa	517 kPa	345 kPa		
			Red.	65 C	65 C	65 C	75 C	85 C	65 C	65 C	65 C	75 C	85 C
S2-1	D	7	0%	2.6-2.3	2.1-1.9	2.0-1.3	--	--	--	--	--	–	--
S2-2	D	7	0%	2 - 1.3 - 5	--	–	--	--	--	--	--	–	--
S2-3	E	7	0%	1.9	1.3	0.85	--	--	2.9	2.2	1.9	–	--
S2-4	E	9	0%	1.7	1.3	0.8	--	--	3.5	3	2.5	–	--
S3-1	E	9	87%	–	--	1.1	--	--	--	--	3.5 - 1.9	–	–
S3-2	E	7	84%	–	--	0.8	0.8	1	--	--	2.8 - 1.9	2.2	2.8
S3-3	C	7	0%	–	--	1.5	2	3	--	--	3.0-1.5	1.7	2.1
S3-4	C	9	0%	–	--	2.2	2.5	3.3	--	--	3.5-1.7	2.0-1.9	2.5-2.0
S3-5	C	7	89%	–	--	1.2-1.4	--	--	--	--	5.0-1.0	–	--
S3-6	C	7	89%	–	--	2.0-1.3	--	--	--	--	7.5-0.8	–	--

All Flux Rates are in cubic meters per square meter day.
Vol. Red. - Volume Reduction

FIGURE 3 - 39

Effect of Pressure on Flux for Site E

(65°C)



from site "E". The results demonstrate that the flux for the THLT-C membrane are higher than for the FLT-C membrane and that pH affects the performance of the THLT-C membrane but not the FLT-C membrane. The results are also interesting in that for the FLT-C membrane the flux decreases in direct proportion to the applied pressure. The flux for the THLT-C membrane is affected less (as a % of flux at 690 kPa) by the decrease in transmembrane pressure than for the FLT-C membrane. This difference is beleived to be the result of reduced membrane compression at lower pressures or may be a result of flux which is limited by a gel layer on the membrane surface which is more severe at higher pressures (see Appendix M).

Figure 3-40 and 3-41 show the effect of temperature on flux for the two membranes from tests conducted using sample from site "E", at an 84% volume reduction, and "C", with no volume reduction. Tests with sample from site "E" showed much higher flux rates for the THLT-C membrane than for the FLT-C membrane. The flux for the THLT-C membrane also increased more than for the FLT-C as the temperature was increased from 65°C to 85°C. Tests with sample from site "C" showed higher flux rates for the FLT-C membrane than for the THLT-C. The FLT-C membrane showed a consistently higher flux during tests conducted with the pH of the feed adjusted up to 9.0 while there was little difference for the THLT-C membrane. The flux for the FLT-C membrane increased more than for the THLT-C membrane as the temperature was increased from 65°C to 85°C.

It is apparent that the two samples have sufficiently different characteristics that the optimum membranes for treating the two samples are different. The nature of this difference may be

FIGURE 3 - 40

Effect of Temperature on Flux for Site E

(345 kPa)

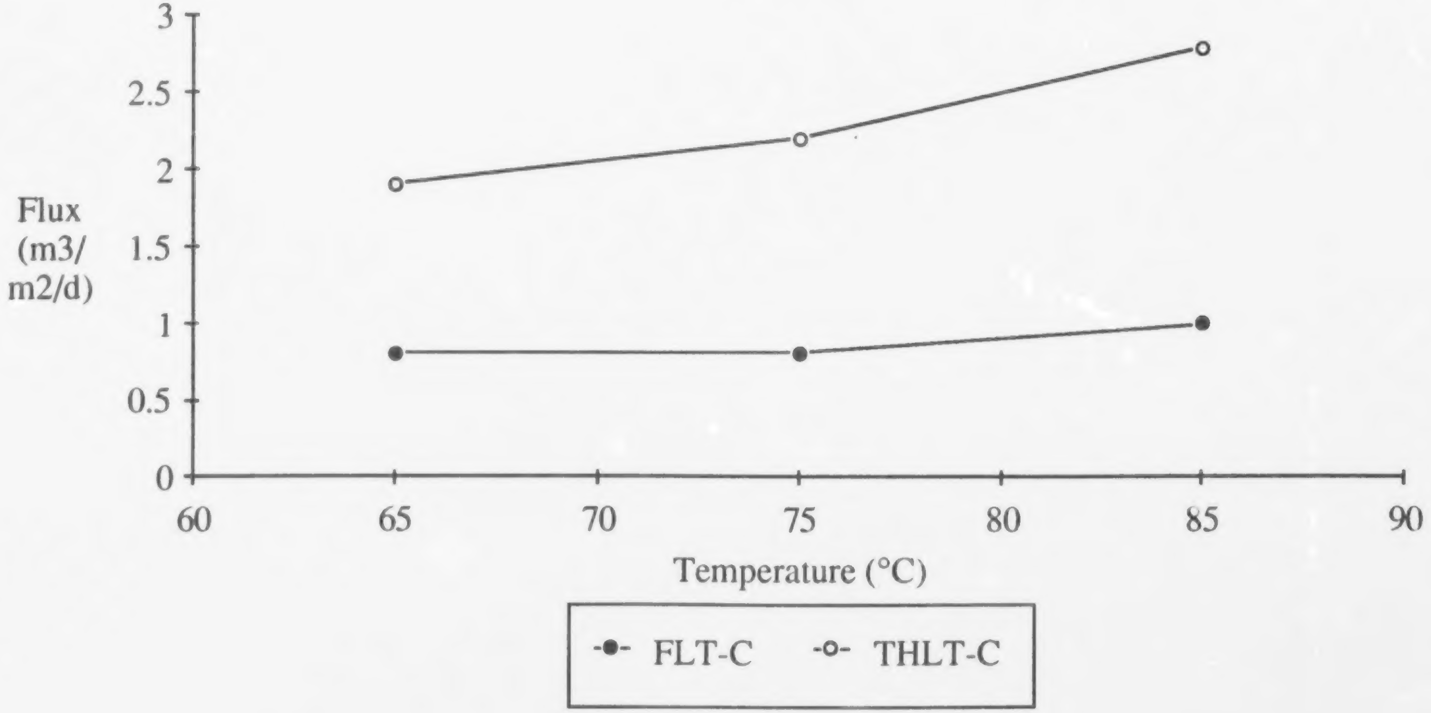
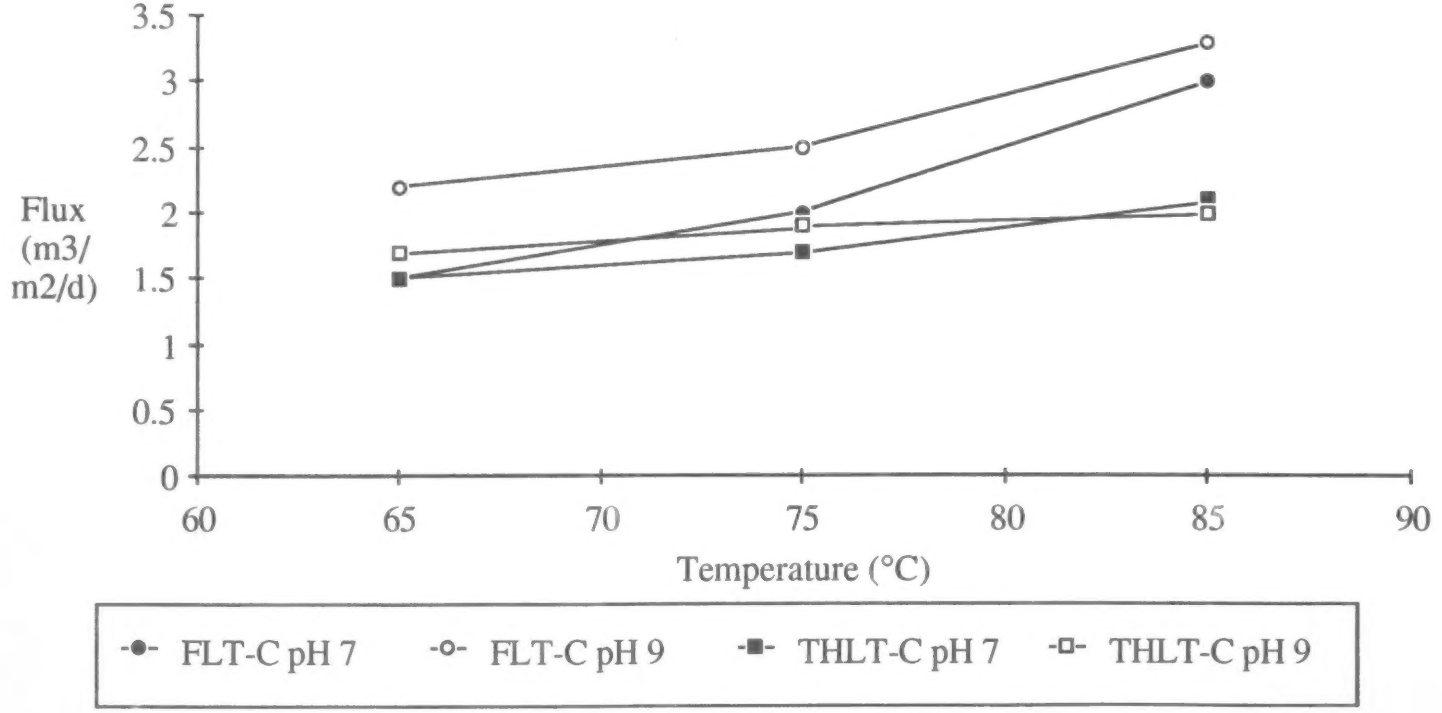


FIGURE 3 - 41

Effect of Temperature on Flux for Site C

(345 kPa)



the molecular weight of organic molecules which are fouling the membranes. With sample from site "E" the fouling material may be sufficiently large that it does not penetrate and foul either membrane and the larger pores of the THLT-C membrane allow for higher flux rates. With sample from site "C" the fouling material may be small enough to penetrate and foul some pores in the THLT-C membrane. The FLT-C with its smaller pores may be more resistant to fouling.

The results do demonstrate that the flux rates of 2.8 and 3.3 m^3/m^2/day can be obtained for site "E" and "C" sample using the optimal membrane for each site and operation at 345 kPa (50 psi) and 85°C.

Table 3-61 shows a summary of feed and permeate quality results for all of the S2 and S3 tests. The results show similar permeate quality for the different tests but do show slight better removal of contaminants with the FLT-C membranes. The FLT-C membrane does have a smaller molecular weight cut off than the THLT-C membrane which shows consistently higher colour in its permeate.

The results show very little removal of conductivity in the membranes and only a very small removal of hardness. If the oil processed with this type of system is to be recycled it will be desirable to have the inorganic consistuents represented by conductivity and hardness to pass through the UF to prevent build up of this material.

The results show consistent and almost complete removal of turbidity in the UF system and the residual amounts present in the permeate are not true turbidity but are actually the result of residual colour in the samples. Some colour is present in all of the permeates

TABLE 3 - 61

Summary of Permeate Quality for Optimization Testing

Test	S2-1	S2-3		S2-4		S3-1		S3-2		
Sample Source	Site D	Site E		Site E		Site E		Site E		
pH of Feed	7	7		9		9		7		
Temperature (°C)	65	65		65		65		65		
Pressure (kPa)	690	690		345		345		345		
Level of Conc.	none	none		61 % VR		87 % VR		84 % VR		
Membrane	FLT-C	FLT-C	THLT-C	FLT-C	THLT-C	FLT-C	THLT-C	FLT-C	THLT-C	THLT-C1
Conductivity (umho)										
Feed	19.5	7.1	7.1	6.8	6.8	6.8	6.8	7.1	7.1	7.1
Permeate	18.3	5.5	6.1	5.0	5.7	6.9	7.0	6.6	6.5	6.4
Turbidity (NTU)										
Feed	16	70	70	340	340	340	340	70	70	70
Permeate	1.6	4.5	0.9	3.0	2.7	5.0	4.0	4.6	3.4	4.7
Hardness (mg/l)										
Feed	1,284	97	97	97	97	97	97	97	97	97
Permeate	1,077	42	55	60	62	66	68	82	82	83
Colour (APHA units)										
Feed	1,100	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Permeate	150	275	275	140	350	400	500	375	425	425
Ext. Oils (mg/l)										
Feed	25	720	720	720	720	720	720	720	720	720
Permeate	<10	3	8	12	13	11	<10	<10	<10	11
Surfactant (mg/l)										
Feed	18	36	36	36	36	36	36	36	36	36
Permeate	12	31	33	16	24	27	28	32	33	30

TABLE 3 - 61 (continued)

Summary of Permeate Quality for Optimization Testing

Test	S3-3		S3-4		S3-5		S3-6	
Sample Source	Site C		Site C		Site C		Site C	
pH of Feed	7		9		7		7	
Temperature (C)	65		65		65		65	
Pressure (kPa)	345		345		345		345	
Level of Conc.	none		none		89 % VR		87% VR	
Membrane	FLT-C	THLT-C	FLT-C	THLT-C	FLT-C	THLT-C	FLT-C	THLT-C
Conductivity (umho)								
Feed	12.2	12.2	11.4	11.4	12.2	12.2	12.2	12.2
Permeate	11.4	11.2	10.9	11.3	11.6	11.8	12.1	11.9
Turbidity (NTU)								
Feed	82	82	68	68	82	82	82	82
Permeate	10.0	5.5	3.5	4.0	2.7	2.5	3.4	1.7
Hardness (mg/l)								
Feed	257	257	221	221	257	257	257	257
Permeate	NA	NA	NA	NA	208	216	232	229
Colour (APHA units)								
Feed	1,750	1,750	2,500	2,500	1,750	1,750	1,750	1,750
Permeate	175	200	125	275	325	500	550	650
Ext. Oils (mg/l)								
Feed	26	26	22	22	26	26	26	26
Permeate	NA	NA	NA	NA	<10	<10	<10	<10
Surfactant (mg/l)								
Feed	35	35	21	21	35	35	35	35
Permeate	NA	NA	NA	NA	18	21	23	23

and is the result of residual soluble organic material which has a molecular weight of less than several thousand.

The removal of extractable oils (method defined in Appendix A) is almost complete for all runs, although some residual amount is measured near the detection limit of the method. The amounts measured as being present are the result of organic held upon the filter used in the procedure since it is unlikely that permeate from a 2,000 molecular weight membrane could contain only truly suspended material.

Surfactant material (as defined in the method in Appendix A) is present in all of the feeds tested and most of this material pases through the membrane. This surfactant material is thought to be of a small molecular weight <1,000-2,000 and accounts for most of the colour. The fact that the surfactant appears to pass through the membrane may be used to reduce the need for emulsion breaking chemicals to break the emulsion which remains in the UF concentrate. The surfactant does, however, contribute to colour and foaming of the water generated which will need to be considered in further processing of this water.

4.0 ECONOMIC ASSESSMENT

4.1 Design Basis

Cost estimates have been prepared for conventional and membrane based processes for the treatment of produced water effluent from a high temperature separator (HTS) or free water knockout (FWKO) unit in a typical steam stimulation heavy oil recovery operation. The processes costed include only the step required to reduce oil to acceptable levels for further treatment such as hot lime softening and/or ion exchange softening.

The capacities of the processes are based on the same capacity system as was used by CH2M HILL in their 1982 report, "Generation of Steam Using Low Grade Fuels and Field Produced Water for In-Situ Oil Recovery". The once through 80% boiler in the CH2M Hill report was rated at 73 MW or 250 m BTU/h and required a feed of approximately 500,000 US gallons per day (USGPD). All processes in this report have been designed to produce 500,000 US GPD of boiler feed water.

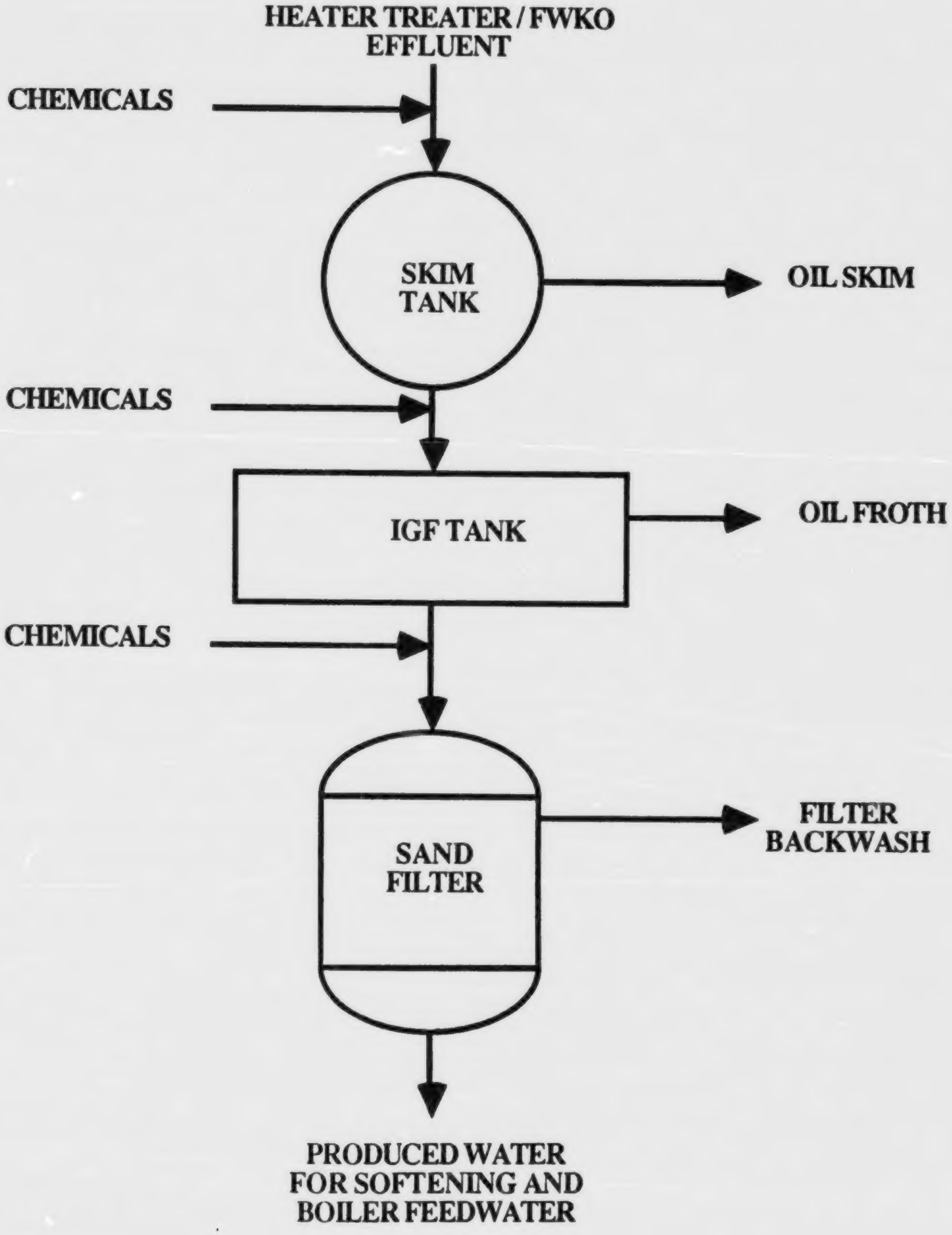
4.1.1 Conventional Oil Removal Process

The design of the process used for conventional treatment were developed based on information available on present treatment practices from the literature and contacts with oil industry representatives. A flow schematic for the produced water treatment scheme using the conventional oil removal process is shown in Figure 4-1.

The flow of produced water from the HTS or FWKO is first treated in a skim tank with top oil and bottom solids removal.

FIGURE 4 - 1

CONVENTIONAL PROCESS FOR OIL REMOVAL FROM PRODUCED WATERS


HEATER TREATER / FWKO EFFLUENT
CHEMICALS
SKIM TANK
OIL SKIM
CHEMICALS
IGF TANK
OIL FROTH
CHEMICALS
SAND FILTER
FILTER BACKWASH
PRODUCED WATER FOR SOFTENING AND BOILER FEEDWATER

Demulsifying chemicals are added before this tank to encourage agglomeration of the oil. The effluent from the skim tank is then treated with additional chemicals and passes into the induced gas floatation (IGF) unit. The effluent from the IGF is then chemically treated and filtered in a pressurized sand filter system.

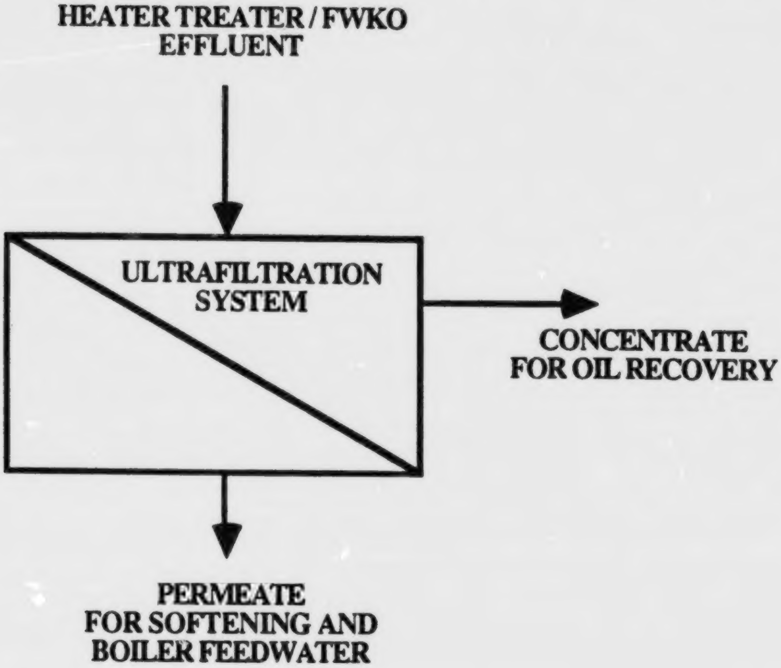
Cost estimates for the individual process steps were obtained from cost correlation tables (Woods, 1980) for the skim tank and from manufacturers quotes for the IGF (Wemco #66) and Sand Filter (Emco). The total installed costs for process equipment were developed using factors of the purchase costs to estimate the other direct and indirect costs of equipment. The installed costs include all costs associated with the facility including foundations, instruments, piping, insulation, buildings, and services, as well as construction and field expenses, engineering, and contractors fees. The chemical requirements and costs for each stage of the process were based on information from a current chemical supplier to the oil industry (Baker Oil Treating division of Magnachem Ltd.). Design parameters used in developing these costs are outlined in the detailed cost breakdown in Appendix K.

4.1.2 Membrane Based Oil Removal Processes

A flow schematic for produced water treatment using membrane based technology for oil removal is shown in Figure 4-2. The membrane processes costed are designed to treat the effluent from an HTS or FWKO unit to remove oil before further treatment. The costs for the membrane systems are based on ZENON's up-to-date cost information for membrane systems and represents a manufacturer's actual selling price.

FIGURE 4 - 2

MEMBRANE PROCESS FOR OIL REMOVAL FROM PRODUCED WATERS


HEATER TREATER / FWKO
EFFLUENT
ULTRAFILTRATION
SYSTEM
CONCENTRATE
FOR OIL RECOVERY
PERMEATE
FOR SOFTENING AND
BOILER FEEDWATER

Again cost factors were used to develop the total installed equipment cost.

In treatability testing with samples of produced water from several EOR field locations, flux rates in excess of 3 m^3/m^2/day have been maintained for extended (>1 week) periods of time. Flux rates from other sites have been lower (1 - 2 m^3/m^2/day). In order to examine the sensitivity of membrane process costs to the flux rates which can be obtained with waters from different locations, systems have been designed and costed based on three different flux rates of 2, 3, and 4 m^3/m^2/day.

Membrane process costs will also be affected by the cost of the membrane modules used in the process initially and the costs of replacement membranes. To examine the sensitivity to this variable, process costs have been developed for three different membrane prices. The first is based on presently available commercial tubular membrane modules which can have the membranes replaced relatively inexpensively. The second assumes tubular membrane modules are developed at a cost of \$25/ft^2 of membrane area. This price is the anticipated selling price of a disposable tubular membrane module. The third case assumes a cost of \$15/ft^2 of membrane for a small tube membrane module. This is a conservative estimate of the price for a small tube ultrafiltration module.

These systems assume an operating pressure of 689 kPa (100 psi) is used in processing the water. If the pressure is reduced to 345 kPa (50 psi) there will be reduction in system costs and a significant reduction in the cost of the membrane modules required.

In all cases the membrane equipment is designed to be explosion proof as will be required when operating adjacent to oil field processing equipment.

The operating costs for the membrane process assume that cleaning will be required every two weeks and that the membrane life will be 2 years. More details of the design parameters used in developing the costs are outlined in the detailed cost breakdown in Appendix L.

The quality of the effluent from both the conventional and the membrane based processes will vary greatly with the level of contaminants in the original feed. An indication of the permeate quality from a membrane system can be obtained by examining the quality of permeate generated during an actual test using produced water from an enhanced oil recovery operation in Western Canada shown in Table 4-1. The membrane system is capable of producing a high quality effluent which has had virtually all suspended oil and solids removed. Significant quantities of large dissolved organic molecules are also removed in the membrane process.

The quality of the effluent produced from the conventional process will vary greatly with the chemical additives used and may be quite poor if dosages are incorrect or upsets occur.

4.2 Process System Costs

The capital and yearly operating costs for the conventional and membrane based treatment processes are shown in Table 4-2. Figure 4-3 shows the yearly costs including operating costs and capital costs amortized over 10 years at 11% interest. Figure 4-4 shows the yearly

TABLE 4 - 1

Permeate Quality for Test S3-2, Site "E"

Component	Unit	Original Feed	Composite Permeate*
Conductivity	umho	7.1	6.5
Turbidity	NTU	70	4.7
Colour	APHA	7,500	425
Hardness	mg/l	97	83
Extractable Oil	mg/l	720	11
Surfactant	mg/l	36	30

*Composite Permeate collected during concentration to an 84 % volume reduction.

TABLE 4-2

Capital and Operating Costs For Conventional and Membrane Based Processes for Oil Removal

OIL REMOVAL PROCESS	Module Cost	Assumed Flux (m3/m2d)	Capital Cost ($1,000)	Operating Costs ($1,000/yr.)	Yearly Costs (over 10 yr.) ($1,000)	Yearly Costs (over 5 yr.) ($1,000)
CONVENTIONAL	---	---	$1,573	$434	$702	$859
MEMBRANE	High	4.0	$1,563	$221	$487	$643
		3.0	$2,084	$255	$609	$818
		2.0	$2,932	$382	$881	$1,174
	Med	4.0	$1,004	$254	$425	$525
		3.0	$1,339	$298	$526	$660
		2.0	$1,884	$447	$768	$956
	Low	4.0	$814	$223	$361	$443
		3.0	$1,085	$257	$442	$550
		2.0	$1,527	$386	$645	$798

To develop yearly costs, capital costs are amortized at 11 % interest over 10 years and 5 years.

FIGURE 4 - 3

Yearly Costs for Conventional and Membrane Based Processes for Produced Water Treatment (10 year amortization of capital)

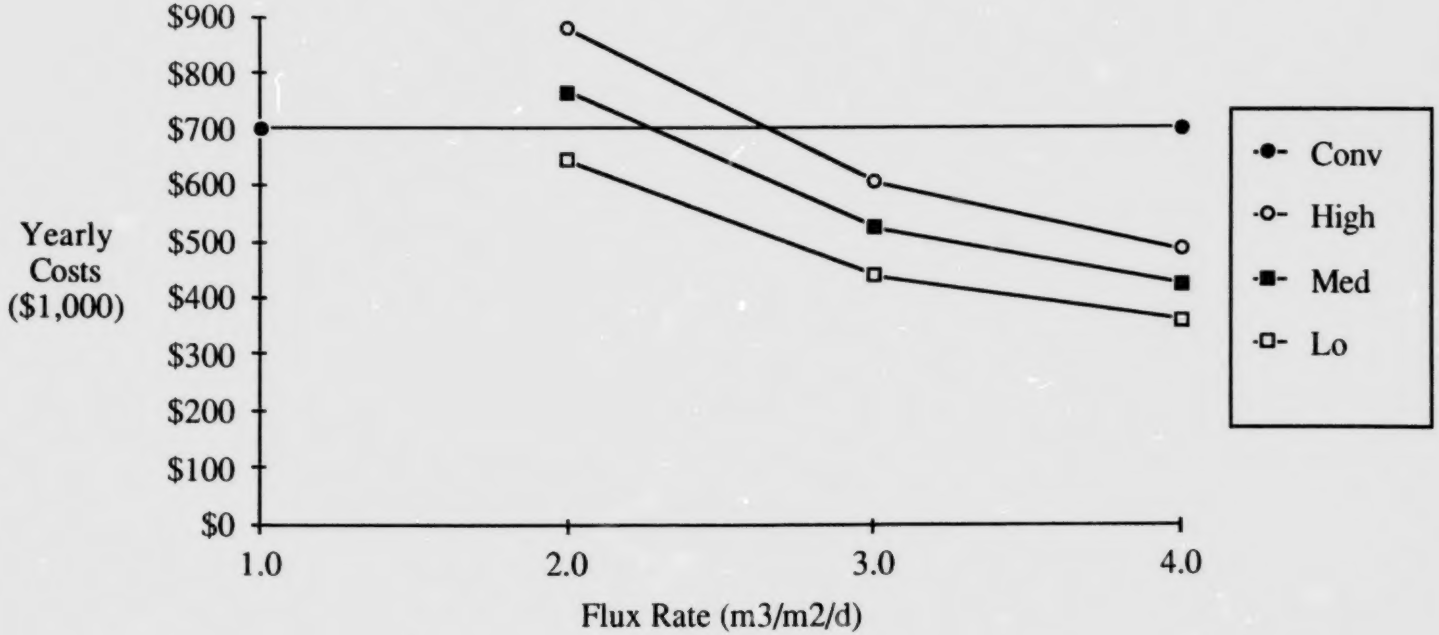
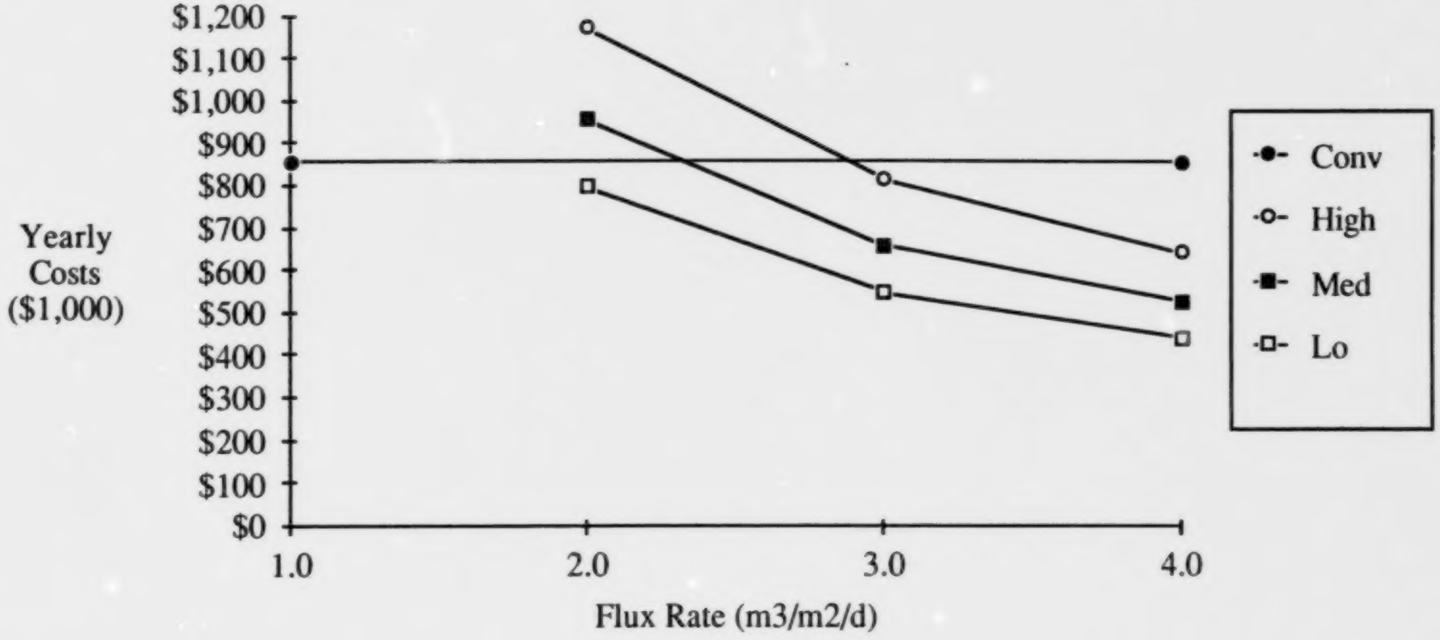


FIGURE 4 - 4

Yearly Costs for Conventional and Membrane Based Processes for Produced Water Treatment (5 year amortization of capital)



costs with the capital costs amortized over 5 years.

Details of the costs developed for conventional and membrane technology are presented in Appendix K and Appendix L.

The installed capital cost of the conventional oil removal process is $1,572,500 and operating costs are $434,300 per year. The membrane based processes designed with the most expensive membranes have capital costs of $1,563,000, $2,084,000, and $2,932,000 for assumed flux rates of 4, 3, and 2 m^3/m^2/day. The yearly operating costs for all the membrane based processes are considerably less than for the conventional process. As a result of this lower operating expense, the yearly operating costs for systems with assumed flux rates of 4 and 3 m^3/m^2/day are less than for the conventional process. The high capital expense of the system using the most expensive membranes and the low flux rate of 2 m^3/m^2/day results in yearly operating costs greater than for the conventional process.

The medium priced membrane systems have significantly lower capital costs but the operating expenses are slightly higher than for the systems using the high priced membrane. The high priced membrane case uses membrane modules which are expensive initially but can have just the membranes replaced at a small cost. The medium priced membrane case uses modules which although less expensive, must be replaced entirely to change membranes. The resultant yearly operating expenses for the medium priced system are less than the conventional process for assumed flux rates of 4 and 3 m^3/m^2/day and (75 gfd) and slightly higher for an assumed flux of 2 m^3/m^2/day (50 gfd.)

The lower priced membrane modules as may be achieved using small tube ultrafiltration modules results in low capital and operating expenses and a process which is economical relative to the conventional process even at flux rates of 2 m^3/m^2/day (50 gfd.)

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

High Temperature Tests with Flat Sheet Test Cells

- Low turbulence in the NRC flat sheet test cells resulted in the formation of a gel layer on the membrane surface which severely limited the flux rate obtained.
- Changes in the emulsion characteristics at high temperatures or low flow conditions appear to have caused more severe gel layer formation and a decrease in flux for most membranes above 65°C in the NRC flat sheet test cell.

Tubular Membrane Testing with Site "A" Sample

- Membranes in tubular configurations obtained much higher and more stable flux rates than the same membranes in the NRC flat sheet test cell configuration.
- CHP-TFC, HPC, and Polyolefin (PO) membranes obtained more stable flux rates than polyethersulphone (PES), polyvinylfluoride (PVDF) or CHP-CA membranes with wellhead produced water from Site "A". Flux rates of 5 m^3/m^2d (120 gfd) were obtained for extended periods of time (> 7 days).
- CHP-TFC membranes showed slightly higher rejections of contaminants than polyethersulphone, CHP-CA, and HPC and significantly higher rejections than the polyolefin membrane tested.
- The CHP-TFC membrane was able to reject virtually all turbidity, suspended solids and suspended organics. Ninety

percent of the TOC, 99% of colour, and 89% of the hardness were also be rejected.

Tubular Membrane Testing with Different Produced Water Samples

- High stable flux rates like those obtained with wellhead emulsion from site "A" in earlier work were obtained with samples from only two of seven other field location.
- Results from testing conducted at Devon using relatively fresh (<3 days old) samples of produced water did not show significant differences from tests conducted in Burlington with older sample of the produced water.
- The results showed low or 1.0 - 3.0 m^3/m^2/day flux rates for other samples of produced water containing high and low levels of oil in the feed.
- The flux rates which can be obtained and maintained over an extended period of time appear to be dependent on the stability of the emulsion present rather than the actual level of oil present.

In House System Optimization

- Inorganic fouling from a high level (>2,000 mg/l) of suspended solids (SS) caused fouling with a sample of produced water from a site where previous samples with lower SS had obtained high stable flux rates.
- Tests with a new THLT-C membrane demonstrated that a significant improvement (60%) in flux is possible with one produced water which show low flux rates with the FLT-C

membrane used earlier.

- Increasing the pH of a produced water sample resulted in a 20% increase in flux over unadjusted produced water with the THLT-C membrane.
- Membrane performance with a different emulsion showed superior performance with the FLT-C membrane over the new THLT-C membrane.
- Operation at lower pressures of 345 kPa (50 psi) do not result in as significant a decrease in flux as had been anticipated and may result in improved economics by decreasing system and membrane costs.
- Increasing the operating temperature from 65°C to 85°C has resulted in an increase in flux rates of up to 50%.

Economic Assessment

- The cost (including operating costs and ammortized capital cost) for a membrane based process for oil removal from produced water is competetive with conventional processes at flux rates greater than 3.0 m^3/m^2/day for even the most expensive membrane module.
- Significant improvements in the economics of the membrane process can be made by reducing the cost of the membrane modules used. Flux rates of 2 m^3/m^2/day can be competative with conventional treatment with the lowest price module.

Overall

- Ultrafiltration membrane systems are capable of removing virtually all suspended oil and solids from oil field produced waters. Dissolved surfactant and inorganic material is not removed in the membrane process.
- Stable flux rates in excess of 3.5 m^3/m^2/day (85 gfd) were obtained in 1/2 inch tubular membrane systems using CHP-TFC type membranes with samples of produced water from three of eight sites tested at 65°C and 690 kPa operation. Flux rates for other samples were lower but still all in excess of 1.0 m^3/m^2/day.
- Optimization of the membrane formulation and increasing the operating temperature to 85°C have resulted in significant improvements in membrane flux rates for samples which previously obtained low flux rates.
- Further optimization of sample pH have also yielded significant improvements in system performance.
- Operation at a lower trans membrane pressure of 345 kPa will not cause as significant a decrease in flux as was thought earlier and may reduce overall system costs.
- Membrane performance is very site specific but flux rates in excess of 2.8 m^3/m^2/day have been obtained at an operating pressure of 345 kPa and temperature of 85°C with two samples, from sites which previously showed less than 1.5 m^3/m^2/day.
- Optimum membranes were different for two of the sites tested.

5.2 Recommendations

- The results of this report should be reviewed in detail with operators of produced water treatment processes to assess in more detail how their site specific needs and requirements can be satisfied by the capabilities of ultrafiltration systems.
- Testing should be conducted at a field location in Western Canada to demonstrate the capabilities of the UF system and obtain data from long term operation with feed directly from a produced water treatment process.
- Work should be conducted on the development of a low cost membrane module which will be capable of handling temperatures of 85°C for extended periods of time.

6.0 REFERENCES

ZENON Environmental Inc. (1985) "Technical and Economic Assessment of the Application of Membrane Technology for Treating Oil/Water/Mineral Emulsions", Report Prepared for energy Mines and Resources, CANMET/ERL, Contract # 0SQ83-00203.

Volume

2

ZENON

ZENON Environmental Inc.

CONTRACT SERIAL NUMBER: OSQ85-00194

MEMBRANE PROCESSING OF OIL FIELD PRODUCED WATER FOR ENHANCED OIL RECOVERY (EOR) STEAM GENERATION

FINAL REPORT

VOLUME II - APPENDICES

Report Prepared for

CANMET/ERL Energy Mines & Resources

Prepared by

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164 pp

June 10, 1987

File No. C0853074

DDS File No. 03SQ.23440-5-9111

MICROMEDIA

SUMMARY OF APPENDICES

Appendix A - Analytical Procedures

This appendix outlines the analytical procedures throughout this work and shows a comparison of results for oil as measured by the two methods used.

Appendix B - Results of High Temperature Membrane Testing with NRC Cells

This appendix contains raw data for the three high temperature tests conducted using the NRC test cells.

Appendix C - Rectangular Flat Sheet Membrane Testing Results

This appendix contains a description and results for additional testing conducted using a rectangular flat sheet test cell which was outside the actual scope of work for this contract. The results demonstrated that flux rates through identical membranes could be a full order of magnitude higher with a higher level of turbulence in the membrane module.

Appendix D - Reynolds Number Calculation

This appendix contains an outline of the calculation of the reynolds numbers for the NRC test cell and the one half inch tubes.

Appendix E, F, G, H, I & J

These appendices contain data from all of the tubular and spiral membrane testing as well as the results of salt water rejection tests conducted before some of the tests.

Appendix K - Detailed Cost Breakdown For Conventional Process

This appendix contains the design parameters and details of the costs for conventional produced water treatment process.

Appendix L - Detailed Cost Breakdown For Membrane Processes

This appendix contains the design parameters and details of the costs for a membrane based produced water treatment process.

Appendix M - Operating Strategies For Oily Water Emulsion Concentration by UF

This appendix outlines operating strategies which will affect the performance of UF membrane systems treating oily water. Techniques for enhancing the flux rate and restoring lost flux are discussed.

APPENDIX A

ANALYTICAL PROCEDURES

APPENDIX A

ANALYTICAL PROCEDURES

pH

The pH was determined using an Extech Model 651 digital meter (Extech, Boston, Mass.) following the method described in the operating manual.

Conductivity

The conductivity was determined using YSI Model 32 conductance meter following the method described in the operating manual.

Turbidity

The turbidity of the samples was determined using a HF Instruments Model DRT 1000 Turbidimeter as per the instruction manual.

Total Organic Carbon (TOC)

The TOC was determined using a Beckman Model 915 TOC analyzer (Beckman Instruments, Inc., Fullerton, California) following the method described in the operating manual.

Filtered Organic Carbon (FOC)

1) Filter sample through a 0.45 micron member filter.
2) Determine TOC using a Beckman Model 915 TOC analyzer (Beckman Instruments, Inc. Fullerton, California) following method described in operating manual.

Total Suspended Oil (TSO) and Total Suspended Solids (TSS)

1) Filter known volume (V) of sample through a washed, ashed, and preweighed (W_1) Whatman glass fiber filter.
2) Dry filter overnight at 100°C.
3) Weigh filter (W_2).
4) Ash filter. Care must be taken to increase temperature slowly from 150°C to 450°C to volatilize oil without burning. Muffle for 1 hour at 450°C.
5) Weigh filter (W_3)
6) Calculations:

$$TSO = \frac{W_2 - W_3}{V} \qquad TSS = \frac{W_3 - W_1}{V}$$

note : Weight loss at 100°C assumed to be only water - along with water loss there may be a loss of the low-boiling components of the oil - resulting in a low TSO value.

Total Dissolved Solids (TDS) and Total Dissolved Oil (TDO)

1) Weigh crucible (W_1).
2) Transfer all filtrate from TSS + TSO determination of known volume (V) to crucible.
3) Dry crucible overnight at 60°C, dessicate, and weigh (W_2).
4) Ash residual in crucible. Muffle for 1 hour at 450°C.
5) Dessicate and weigh crucible (W_3)
6) Calculations:

$$TDO = \frac{W_2 - W_3}{V} \qquad TDS = \frac{W_3 - W_1}{V}$$

Anion Scan (IC)

Samples were analyzed using Ion Chromatography for Cl, PO_4, B_r^-, SO_4, NO_3, NO_2, and F. Results were reported in mg/L.

Cation Scan (DCP)

The samples were analyzed by direct coupled plasma for Ag, Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sr, V, Zn. Results were reported in mg/L.

Silica

Initial silica values were determined on an aliquot of sample following the procedure described in AWWA Standard Methods 16/C (Molybdosilicate Method). Accurate determination of total silica in the raw emulsion was difficult without filtration of the sample as a result of interference from oil and other components. For the long term testing with different samples and those which followed, silica was measured as silicon by direct coupled plasma and converted to silica by multiplying by 60/28.

Calculated Hardness

Total hardness is calculated by multiplying the concentration of Ca and Mg by the proper factor to obtain equivalent calcium carbonate, and by summing these $CaCO_3$ concentrations. To obtain the $CaCO_3$ equivalent (mg/L) of Ca and Mg, the concentrations were multiplied by 2.5 and 4.116 respectively.

Extractable Oil (Methylene Chloride Extractable)

Methylene chloride extractable oil was measured by filtering the sample using a vacuum pump through a 0.45 glass fiber filter paper. The volume of the sample was recorded from the filtrate volume. The filter was then placed in the original sample jar and the filter apparatus was rinsed with methylene chloride. The wash solvent used was placed into the jar. The filter paper was allowed to soak in the solvent for at least one hour in the covered jar. One gram of anhydrous Na_2SO_4 was placed in a phase separating filter cone and the sample was poured through into a clean graduated cylinder. The sample jar containing the filter paper was rinsed several times until the wash solvent was clear.

The concentration of bitumen in the solvent was determined using a spectrophotometer at a wave length of 450 nm. The instrument zero was set using uncontaminated methylene chloride and values were compared against a calibration curve generated with methylene chloride containing 0 - 500 mg/L of bitumen. The solvent containing bitumen to be determined was diluted with additional methylene chloride if it was outside the calibration range.

The value for oil in the original sample was calculated from the original sample volume and concentration of oil and volume of the solvent.

Oil and Surfactant

Oil and surfactant measurements were obtained by isolating acidic surfactant components and the neutral oils by back extraction and measuring these components gravimetrically. An outline of the procedure for back extraction is shown in Figure A-1. Figure A-2 shows a comparison of values obtained for extractable oil and oils measured gravimetrically by this method.

Colour

Colour was measured using a Hach Colour Test Kit, Model CO-1, using the method outlined in the test kit. Samples were diluted as required to obtain colour in the range measureable with the test kit. The units measured are apparent colour in APHA Platinum Cobalt Units.

FIGURE A - 1

Separation of Oil and Surfactant for Gravimetric Analysis

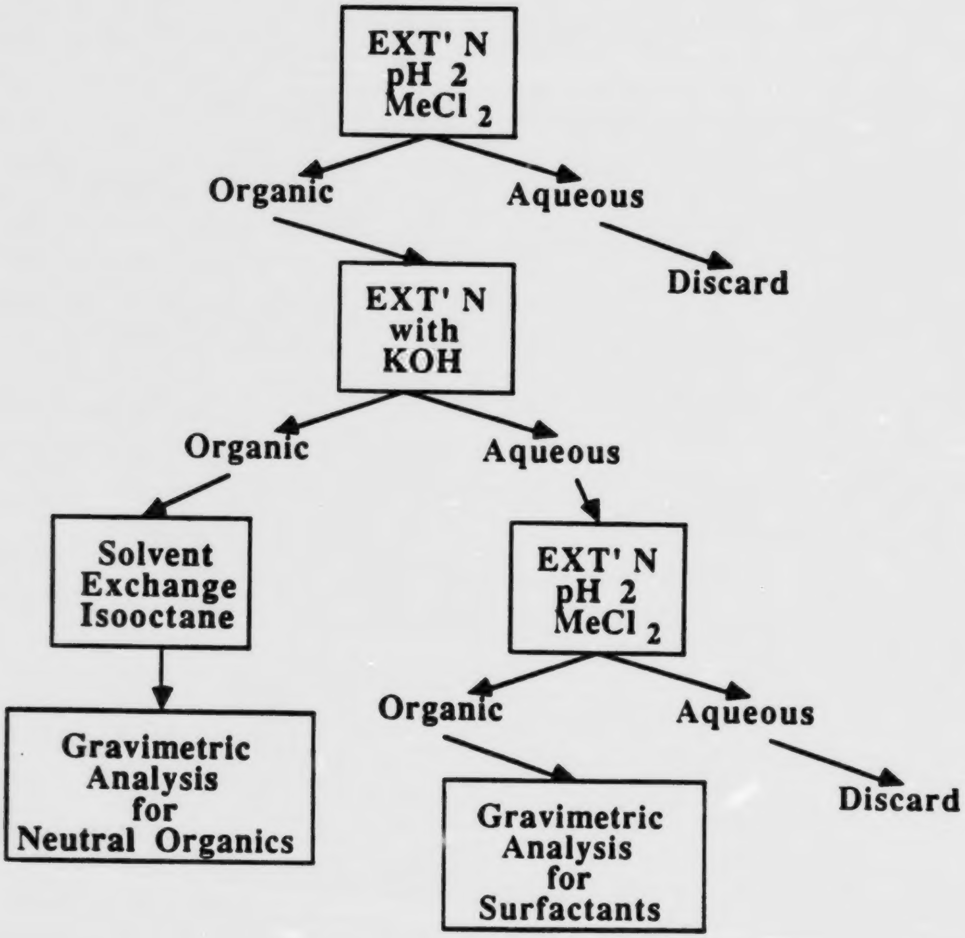
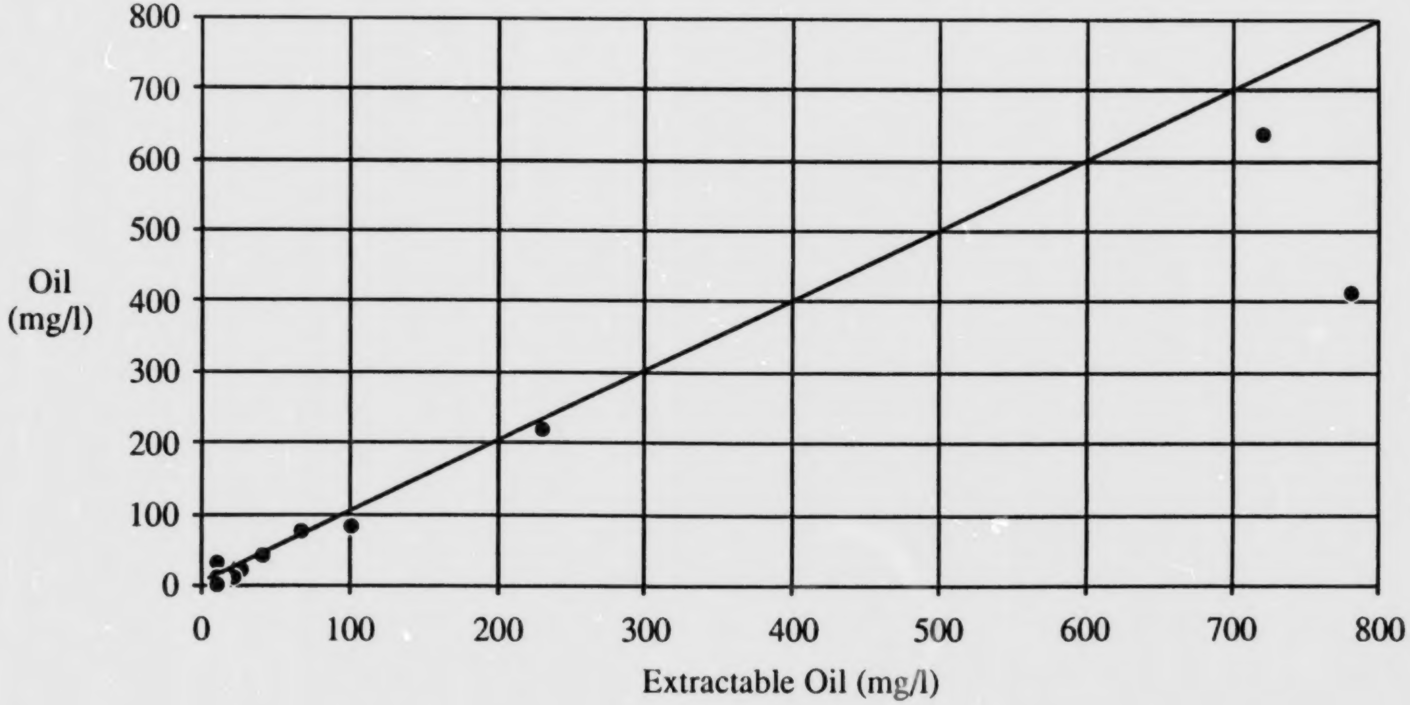

EXT' N
pH 2
MeCl 2
Organic
Aqueous
Discard
EXT' N
with
KOH
Organic
Aqueous
Solvent
Exchange
Isooctane
Gravimetric
Analysis
for
Neutral Organics
EXT' N
pH 2
MeCl 2
Organic
Aqueous
Discard
Gravimetric
Analysis
for
Surfactants

FIGURE A - 2

Comparison of Oil Values by Different Methods



APPENDIX B

RESULTS OF HIGH TEMPERATURE MEMBRANE TESTING WITH NRC CELLS

TASK #1
EMR- PRODUCE WATER TESTING
RUN #1 65 DEGREES CELCIUS
100 PSI JANUARY 15 1986
2 L/MIN. 65 C

				CELL #1			CELL #2			CELL #3	
TIME (MIN.)	FEED COND.	FEED pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	1.010	8.700	2.750	.401	8.230	2.610	.390	8.230	5.030	.390	8.230
60	1.060	8.680	2.300	.380	8.270	2.000	.375	8.200	4.030	.368	8.210
120	1.050	8.710	1.800	.397	8.250	1.530	.394	8.210	3.180	.395	8.200
300	.967	8.820	1.280	.392	8.300	1.050	.390	8.260	2.260	.375	8.290
1080	.999	8.900	.625	.426	8.350	.525	.428	8.330	1.125	.409	8.410
1140	.998	8.910	.575	.429	8.350	.483	.431	8.350	1.058	.412	8.400
1200	N/A	N/A	.591	N/A	N/A	.508	N/A	N/A	1.088	N/A	N/A
1260	N/A	N/A	.575	N/A	N/A	.492	N/A	N/A	1.050	N/A	N/A
1320	1.057	8.870	.567	.439	8.130	.483	.442	8.150	1.050	.429	8.280
1380	1.089	88.000	.563	.452	8.110	.475	.445	8.220	1.025	.429	8.260
1440	1.076	8.830	.553	.448	8.120	.466	.454	8.040	1.000	.442	8.150

		CELL #4			CELL #5			CELL #6			CELL #7	
TIME (MIN.)	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	1.420	.395	8.230	2.000	.379	8.150	1.350	.245	8.020	2.700	.409	8.230
60	1.100	.378	8.210	1.530	.372	8.160	1.330	.224	8.000	2.100	.405	8.260
120	1.620	.400	8.210	1.180	.395	8.130	1.150	.240	8.010	1.550	.410	[illegible]
300	.520	.406	8.240	.820	.399	8.240	.870	.276	8.200	1.020	.408	N/A
1080	.208	.454	8.260	.421	.456	8.400	.421	.370	8.350	.517	.434	[illegible]
1140	.171	.469	8.250	.388	.459	8.410	.392	.680	8.370	.467	.445	[illegible]
1200	.179	N/A	N/A	.400	N/A	N/A	.413	N/A	N/A	.483	N/A	N/A
1260	.183	N/A	N/A	.392	N/A	N/A	.392	N/A	N/A	.453	N/A	N/A
1320	.183	.471	8.100	.385	.468	8.290	.395	.381	8.300	.463	.456	[illegible]
1380	.175	.466	8.000	.383	.468	8.230	.375	.387	8.230	.440	.462	[illegible]
1440	.167	.486	8.010	.375	.481	8.160	.368	.396	8.170	.417	.461	[illegible]

NOTE: CONCENTRATION FACTOR = 1.22 (V.R.= 17.96%) AT T= 1440

TASK #1
EMR- PRODUCE WATER TESTING
RUN #2 75 DEGREES CELCIUS
100 PSI JANUARY 15 1986
2 L/MIN. 75 C

			CELL #1			CELL #2			CELL #3		
TIME (MIN.)	FEED COND.	FEED pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	.987	8.550	2.530	.482	8.000	2.280	.492	8.020	3.700	.516	8.020
60	1.029	8.570	1.430	.480	8.030	1.270	.482	8.010	1.970	.473	8.020
90	1.032	8.600	.997	.478	8.020	.867	.478	8.020	1.240	.465	8.030
120	1.020	8.450	.790	.638	8.090	.683	.488	8.100	.967	.464	8.070
180	N/A	N/A	.720	N/A	N/A	.620	N/A	N/A	.850	N/A	N/A
210	N/A	N/A	.675	N/A	N/A	.583	N/A	N/A	.780	N/A	N/A
240	1.023	N/A	.683	.452	N/A	.617	.457	N/A	.842	.434	N/A
1020	1.056	N/A	.483	.415	N/A	.429	.416	N/A	.625	.389	N/A
1140	1.079	N/A	.500	.387	N/A	.458	.387	N/A	.669	.365	N/A
1200	1.240	8.730	.492	.415	8.250	.450	.403	8.230	.654	.377	8.210
1260	1.138	8.810	.500	.419	8.300	.458	.410	8.230	.675	.382	8.260
1320	1.255	8.810	.508	.408	7.970	.467	.408	8.050	.692	.382	8.100
1380	1.224	8.850	.533	.399	8.170	.483	.401	8.120	.717	.374	8.100
1440	1.096	8.710	.533	.400	8.080	.475	.401	8.010	.703	.373	8.100

	CELL #4			CELL #5			CELL #6			CELL #7		
TIME (MIN.)	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	1.700	.482	8.100	2.070	.476	8.100	1.800	.304	8.060	1.970	.489	8.150
60	.980	.486	8.130	1.150	.479	8.090	1.050	.371	8.100	1.030	.498	8.130
90	.640	.484	8.120	.683	.475	8.080	.620	.380	8.110	.600	.499	8.140
120	.510	.493	8.040	.517	.488	8.080	.450	.428	8.110	.420	.522	8.120
180	.450	N/A	N/A	.450	N/A	N/A	.383	N/A	N/A	N/A	.383	N/A
210	.425	N/A	N/A	.425	N/A	N/A	.350	N/A	N/A	N/A	.317	N/A
240	.617	.499	N/A	.467	.465	N/A	.400	.414	N/A	.380	.464	N/A
1020	.325	.423	N/A	.383	.409	N/A	.346	.366	N/A	.300	.420	N/A
1140	.316	.386	N/A	.408	.381	N/A	.379	.338	N/A	.323	.402	N/A
1200	.275	.404	8.100	.400	.393	8.160	.375	.350	8.090	.320	.408	8.140
1260	.283	.404	8.130	.408	.399	8.180	.383	.354	8.190	.333	.410	8.050
1320	.283	.408	8.000	.417	.401	8.050	.383	.363	8.070	.317	.434	8.060
1380	.283	.399	8.010	.433	.395	8.150	.400	.349	8.140	.333	.411	8.140
1440	.267	.399	7.910	.425	.392	7.980	.383	.350	8.080	.317	.410	8.140

NOTE: CONCENTRATION FACTOR = 1.14 (V.R. = 12.5%) AT T= 1440

TASK #1
EMR- PRODUCE WATER TESTING
RUN #3 85 DEGREES CELCIUS
100 PSI JANUARY 21 1986
2 L/MIN. 85 C

			CELL #1			CELL #2			CELL #3		
TIME (MIN.)	FEED COND.	FEED pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	1.112	8.630	2.940	.571	8.100	2.920	.546	8.130	3.000	.551	8.130
60	1.150	N/A	1.940	.543	N/A	1.980	.525	N/A	2.030	.525	N/A
90	1.170	N/A	1.550	.510	N/A	1.600	.498	N/A	1.600	.488	N/A
180	N/A	N/A	1.430	N/A	N/A	1.470	N/A	N/A	1.450	N/A	N/A
240	1.198	N/A	.967	.496	N/A	.983	.492	N/A	1.000	.486	N/A
270	N/A	N/A	.780	N/A	N/A	.967	N/A	N/A	.967	N/A	N/A
540	N/A	N/A	.840	N/A	N/A	.867	N/A	N/A	.883	N/A	N/A
1170	N/A	N/A	.607	N/A	N/A	.630	N/A	N/A	.650	N/A	N/A
1230	1.369	N/A	.558	.557	N/A	.568	.549	N/A	.588	.550	N/A
1290	N/A	N/A	.538	N/A	N/A	.550	N/A	N/A	.575	N/A	N/A
1350	N/A	N/A	.538	N/A	N/A	.542	N/A	N/A	.565	N/A	N/A
1440	1.398	N/A	.521	.578	N/A	.533	.570	N/A	.550	.567	N/A

	CELL #4			CELL #5			CELL #6			CELL #7		
TIME (MIN.)	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH	PERMEATE RATE MLS/MIN.	COND.	pH
30	2.970	.575	8.260	2.800	.556	8.220	2.625	.328	8.180	2.720	.560	8.280
60	2.016	.548	N/A	1.920	.537	N/A	1.970	.362	N/A	1.850	.555	N/A
90	1.625	.511	N/A	1.530	.511	N/A	1.620	.369	N/A	1.480	.509	N/A
180	1.480	N/A	N/A	1.400	N/A	N/A	1.475	N/A	N/A	1.370	N/A	N/A
240	1.020	.503	N/A	.967	.497	N/A	.967	.415	N/A	.930	.519	N/A
270	.980	N/A	N/A	.917	N/A	N/A	.960	N/A	N/A	.917	N/A	N/A
540	.867	N/A	N/A	.833	N/A	N/A	.850	N/AS	N/A	.833	N/A	N/A
1170	.617	N/A	N/A	.617	N/A	N/A	.600	N/A	N/A	.633	N/A	N/A
1230	.546	.564	N/A	.558	.553	N/A	.550	.492	N/A	.553	.577	N/A
1290	.533	N/A	N/A	.550	N/A	N/A	.545	N/A	N/A	.542	N/A	N/A
1350	.525	N/A	N/A	.542	N/A	N/A	.533	N/A	N/A	.533	N/A	N/A
1440	.508	.586	N/A	.529	.576	N/A	.521	.533	N/A	.525	.583	N/A

NOTE: CONCENTARTION FACTOR= 1.32 (V.R.= 24.39%) AT T= 1440.

FLUX RATES FOR SCREENING TEST #1

TEMP.=65 C pH = AS IS (8.7-9.0) PRESSURE = 100

TIME (hours)	CELL #1 HPC-LS #334 FLUX RATE M3/M2 DAY	CELL #2 CHP-NN #349 FLUX RATE M3/M2 DAY	CELL #3 CHP-CA #348 FLUX RATE M3/M2 DAY	CELL #4 E500 FLUX RATE M3/M2 DAY	CELL #5 HPC #339 FLUX RATE M3/M2 DAY	CELL #6 G10 FLUX RATE M3/M2 DAY	CELL #7 CHP-TFC #346 FLUX RATE M3/M2 DAY
0.5	2.98	2.83	5.45	1.54	2.17	1.46	2.92
1	2.49	2.17	4.36	1.19	1.66	1.44	2.27
2	1.95	1.66	3.44	1.75	1.28	1.25	1.68
5	1.39	1.14	2.45	0.56	0.89	0.96	1.10
18	0.68	0.57	1.22	0.23	0.46	0.46	0.56
19	0.62	0.52	1.15	0.19	0.42	0.42	0.51
20	0.64	0.55	1.18	0.19	0.43	0.45	0.52
21	0.62	0.53	1.14	0.20	0.42	0.42	0.49
22	0.61	0.52	1.14	0.20	0.42	0.43	0.50
23	0.61	0.51	1.11	0.19	0.41	0.41	0.48
24	0.60	0.50	1.08	0.18	0.41	0.40	0.45

FLUX RATES FOR SCREENING TEST #2

TEMP.=75 C pH = AS IS (8.5-8.8) PRESSURE = 100

TIME (hours)	CELL #1 HPC-LS #334 FLUX RATE M3/M2 DAY	CELL #2 CHP-NN #349 FLUX RATE M3/M2 DAY	CELL #3 CHP-CA #348 FLUX RATE M3/M2 DAY	CELL #4 E500 FLUX RATE M3/M2 DAY	CELL #5 HPC #339 FLUX RATE M3/M2 DAY	CELL #6 G10 FLUX RATE M3/M2 DAY	CELL #7 CHP-TFC #346 FLUX RATE M3/M2 DAY
0.5	2.74	2.47	4.01	1.84	2.24	1.95	2.13
1	1.55	1.38	2.13	1.06	1.25	1.14	1.12
1.5	1.08	0.94	1.34	0.69	0.74	0.67	0.65
2	0.86	0.74	1.05	0.55	0.56	0.49	0.45
3	0.78	0.67	0.92	0.49	0.49	0.41	0.41
3.5	0.73	0.63	0.84	0.46	0.46	0.38	0.34
4	0.74	0.67	0.91	0.67	0.51	0.43	0.41
17	0.52	0.46	0.68	0.35	0.41	0.37	0.32
19	0.54	0.50	0.72	0.34	0.44	0.41	0.35
20	0.53	0.49	0.71	0.30	0.43	0.41	0.35
21	0.54	0.50	0.73	0.31	0.44	0.41	0.36
22	0.55	0.51	0.75	0.31	0.45	0.41	0.34
23	0.58	0.52	0.78	0.31	0.47	0.43	0.36
24	0.58	0.51	0.76	0.29	0.46	0.41	0.34

FLUX RATES FOR SCREENING TEST #3

TEMP.=85 C pH = AS IS 8.6 PRESSURE = 100

TIME (hours)	CELL #1 HPC-LS #334 FLUX RATE M3/M2 DAY	CELL #2 CHP-NN #349 FLUX RATE M3/M2 DAY	CELL #3 CHP-CA #348 FLUX RATE M3/M2 DAY	CELL #4 E500 FLUX RATE M3/M2 DAY	CELL #5 HPC #339 FLUX RATE M3/M2 DAY	CELL #6 G10 FLUX RATE M3/M2 DAY	CELL #7 CHP-TFC #346 FLUX RATE M3/M2 DAY
0.5	3.18	3.16	3.25	3.22	3.03	2.84	2.95
1	2.10	2.14	2.20	2.18	2.08	2.13	2.00
1.5	1.68	1.73	1.73	1.76	1.66	1.75	1.60
3	1.55	1.59	1.57	1.60	1.52	1.60	1.48
4	1.05	1.06	1.08	1.10	1.05	1.05	1.01
4.5	0.84	1.05	1.05	1.06	0.99	1.04	0.99
9	0.91	0.94	0.96	0.94	0.90	0.92	0.90
19.5	0.66	0.68	0.70	0.67	0.67	0.65	0.69
20.5	0.60	0.62	0.64	0.59	0.60	0.60	0.60
21.5	0.58	0.60	0.62	0.58	0.60	0.59	0.59
22.5	0.58	0.59	0.61	0.57	0.59	0.58	0.58
24	0.56	0.58	0.60	0.55	0.57	0.56	0.57

APPENDIX C

RECTANGULAR FLAT SHEET MEMBRANE TESTING RESULTS

APPENDIX C

RECTANGULAR FLAT SHEET MEMBRANE TESTING RESULTS

INTRODUCTION

Two short term membrane tests were conducted outside the scope of the work of the "Membrane Processing of Oil Field Produced Water for Enhanced Oil Recovery Steam Generation" to determine the effect of different membrane module flow conditions on flux rates. These results are presented for the interest of the Scientific Authority but are outside the requirements of this contract.

EXPERIMENTAL PROCEDURES

Oil-in-water emulsions obtained from the wellhead at Texaco Canada's in-situ heavy oil recovery operation at Fort McMurray early in 1984 were used in these tests.

The test apparatus used here and the NRC test cells are the same as were used for the project "Membrane Processing of Oil Field Produced Water for EOR Steam Generation".

The flat sheet test cell was constructed at ZENON to provide a flat sheet test unit for membrane testing which would have a Reynolds number well in the turbulent range. The membrane area is 5 cm wide and 12.7 cm long. The gap above the membrane is 0.15875 cm (1/16") high.

Two membranes CHP-CA and TFC-G10 were tested in the flat sheet test cell. During the first test, the membrane CHP-CA was placed in the test cell with a flow of 12 L/min at a temperature of 65°C. The permeate was recycled directly back to the process tank and the flux rates were monitored on a regular basis. One sample of permeate was taken and analyzed for TDS. After 24 hours of operation at 65°C the temperature of the feed was increased to 75°C. After a further 24 hours the temperature was increased to 85°C.

A second test was conducted for 24 hours using a sample of membrane G10 at a temperature of 65°C.

RESULTS AND DISCUSSION

The results of the two flat sheet tests along with the results obtained with the same membranes in NRC test cells under identical conditions of temperature and feed are shown in Figure 1. The results showed a significantly high flux rate for both membranes when installed in the flat sheet test cell. For the CHP-CA membrane the increase is almost 7 fold. The G10 membrane had a lower flux rate than was observed in the NRC cell during the initial few hours of operation. The flux through the G10 in the flat sheet however, increased overnight and remained stable above 2 m^3/m^2d. In the NRC cell the flux rate after 18 hours of operation had decreased to about 0.2 m^3/m^2d.

The dissolved solids levels and conductivities of the permeates through G10 and CHP-CS in the flat sheet test cell and in the NRC cell are shown in Table 1. There are no significant differences in the permeate quality between tests in the NRC and flat sheet test cells. The higher flux rates are not accompanied by the passage of greater amounts of contaminants.

Calculations were also performed to determine the Reynolds numbers in the NRC cell and in the flat sheet test unit for comparison

FIGURE 1

Flux Rates for NRC Cell and Flat Sheet Test Unit

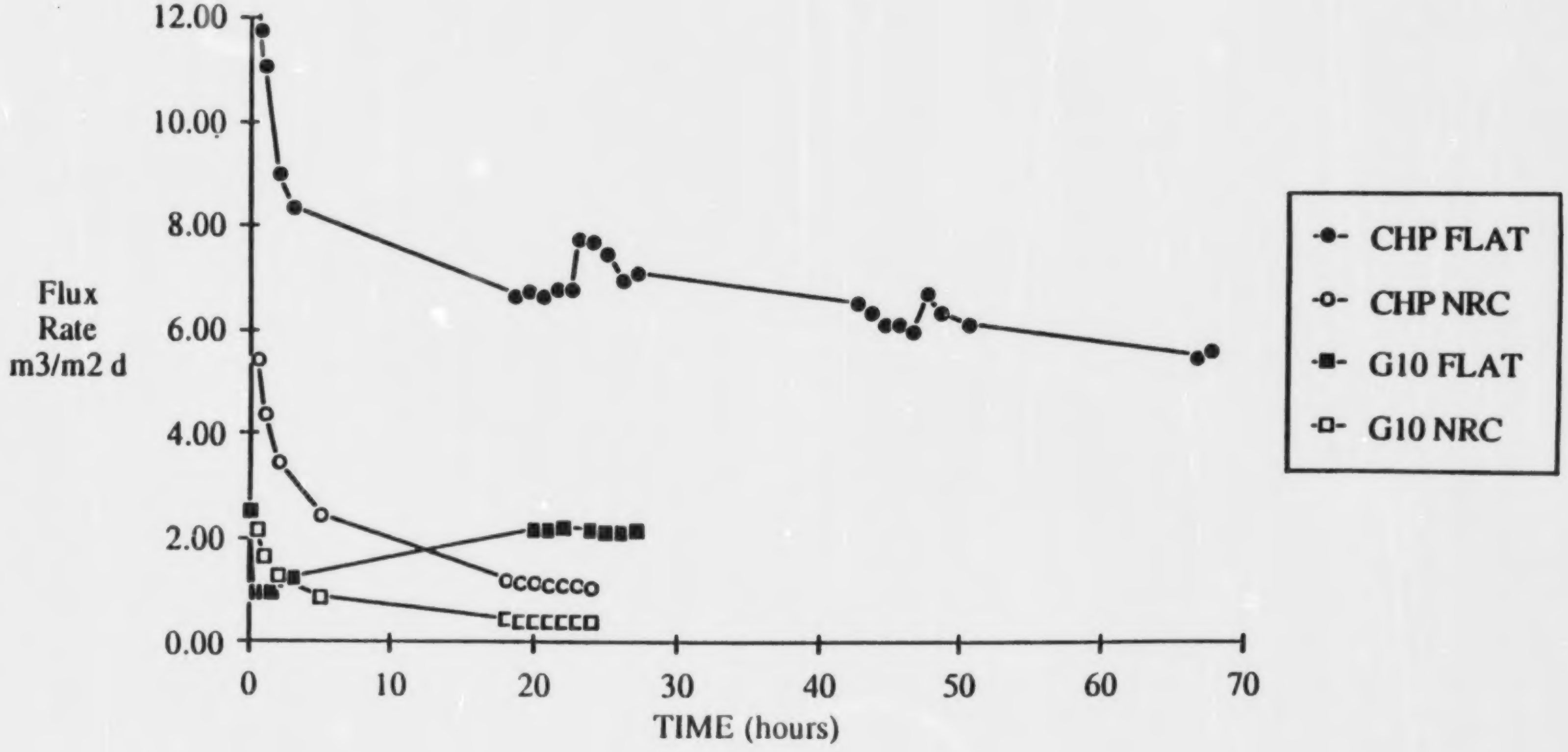


TABLE 1

Permeate Quality for NRC Cell and Flat Sheet Test Cell

Membrane	Temp. (C)	NRC Cell Permeate TDS (mg/l)	Flat Cell Permeate TDS (mg/l)	NRC Cell Permeate Cond.	Flat Cell Permeate Cond.
G10 (TFC)	65	109	123	0.32	0.15
CHP CA	65	195	358	0.4	0.41
CHP CA	75	247	310	0.41	0.375
CHP CA	85	308	283	0.5	0.367

purposes. The assumptions and calculations used in determining Reynolds numbers are presented in the following Appendix. Using the method outlined, the Reynolds number in the NRC cell is approximately 500 - 600 while that for the flat sheet test cell is 7,700. If this method for Reynolds number determination is valid, it could explain the significantly higher flux rates in the flat sheet test unit and supports the idea that gel layer limitations controlled the flux rates during the previous tests in the NRC cells at 85°C. Since the Reynolds number in the 1/2" tubular modules which will be used in the next phase of work are well in the turbulent range, we feel we can expect to achieve that the higher flux rates of the flat sheet test cell. These results will have significant impact on the overall economics of using membranes for this application since the capital and operating costs for membrane systems of this size are an inverse function of the flux rates which can be obtained.

APPENDIX D

REYNOLDS NUMBER CALCULATIONS

REYNOLDS NUMBER CALCULATIONS

REYNOLDS NUMBER EQUATION

$$Re = \frac{LV\rho}{\mu}$$

L = characteristic length (m)

for tubes is diameter
for slot a x b is the hydraulic diameter

$$= \frac{2ab}{a+b}$$

V = fluid velocity (m/s)

Assume: Water at ambient temperature
density = $\rho = 1000$ Kg/m^3
viscosity $\mu = 1.0 \times 10^{-3}$ Kg/ms

$\therefore \quad \rho/\mu = 10^6$ (s/m^2)

FLAT SHEET TEST CELL

Flow is through a slot 5 cm wide by 0.15875 cm (1/16") high. Flow is 12 L/min.

$$L = \frac{2ab}{a+b} = \frac{2 \times (5)(0.15875)}{5.15875}$$

$$= 0.30773 \text{ cm} = 3.0773 \times 10^{-3}\text{m}$$

$V = \frac{Q}{A}$ where Q = flowrate
A = area

$$V = \frac{12{,}000}{5 \times 0.15875} \frac{\text{cm}^3/\text{min}}{\text{cm}^2}$$

$$= 15{,}118 \text{ cm/min} = 252 \text{ cm/sec}$$
$$= 2.52 \text{ m/sec}$$

$$Re = LV \times 10^6$$
$$= (3.0773 \times 10^{-3})(2.52)(10^6)$$
$$= 7{,}755$$

ONE HALF INCH TUBES

Flow of 20 L/min through 1/2 inch tube

$L = 1.27 \text{ cm} = 0.0127 \text{ m}$

$$V = \frac{20{,}000}{\pi\left(\frac{1.27}{2}\right)^2} \quad \text{cm}^3/\text{min}$$

$= 15{,}788 \text{ cm/min} = 263 \text{ cm/sec}$

$= 2.63 \text{ m/sec}$

$Re = (0.0127)(2.63)\ 10^6$

$= 33{,}418$

NRC TEST CELL

At the outer ring of the cell for some small section dr assume to be equivalent to a slot of width πD and height equal to the gap.

gap = 0.025" = 1/40"

= 0.0635 cm

width = $\pi D = \pi(4.159) = 13.066$ cm

flow = 2 L/min

$$L = \frac{2ab}{a+b} = \frac{2(13.066)(0.0635)}{13.066 + 0.0635}$$

$= 0.1264 \text{ cm} = 1.264 \times 10^{-3} \text{ m}$

$$V = \frac{Q}{A} = \frac{2{,}000}{(13.066)(0.0635)} \quad \frac{\text{cm}^3/\text{min}}{\text{cm}^2}$$

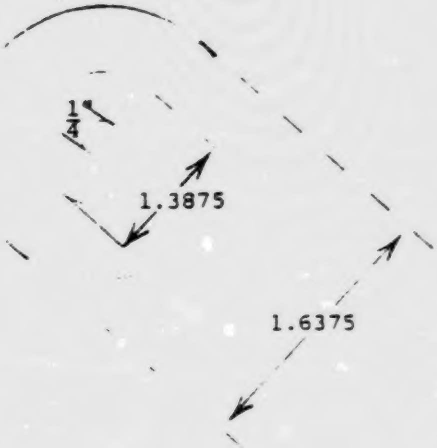
$= 2{,}410.5 \text{ cm/min} = 40 \text{ cm/sec} = 0.402 \text{ m/sec}$

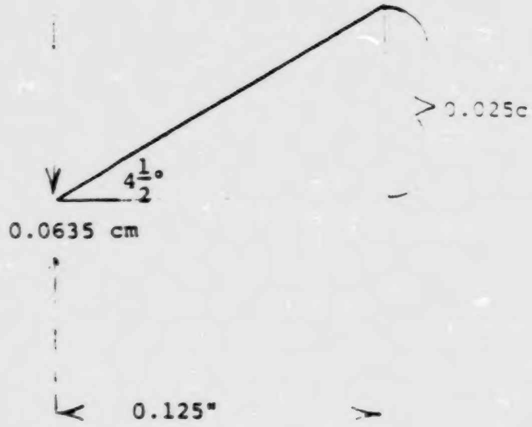
$Re = LV \times 10^6$

$= 1.264 \times 10^{-3}\ (0.402) \times 10^6$

$= 508$

At a radius half way between the outer ring and the outlet assume as before a slot of width πD and height of the gap.





$$\tan 4.5° = \frac{x}{0.125} \qquad x = 0.0098"$$
$$= 0.025 \text{ cm}$$

Width = $\pi D = \pi 1.3875 = 11.07$ cm

flow = 2L/min

$$L = \frac{2ab}{a+b} = \frac{2(0.0885)(11.07)}{11.07 + 0.0885} = 0.1756 \text{ cm}$$

$$= 1.756 \times 10^{-3} \text{ m}$$

$$V = \frac{2{,}000}{(11.07)(0.0885)} = 2{,}041.4 \text{ cm/min} = 0.3402 \text{ m/sec}$$

$$Re = 1.756 \times 10^{-3} (0.3402) \times 10^{6}$$
$$= 597$$

APPENDIX E

FLUX DATA FOR TUBULAR MEMBRANE TESTING WITH SITE "A" WELLHEAD SAMPLE

FLUX DATA FROM TEST NUMBER A1

DATE: Feb. 24, 1986 **MEMBRANE :** PES **FEED :** Site A Wellhead Emulsion

TIME (min.)	FEED COND.	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (l)	% VOL. RED.
		PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. PERM. (l)		
15	2.29	312	2.08	4.68	284	2.17	4.26	8.94	17.9
30	N/A	304	N/A	4.56	270	N/A	4.06	17.56	35.1
45	2.149	298	1.96	4.465	269	2.06	4.04	26.06	52
60	N/A	286	N/A	4.29	265	N/A	3.975	34.33	68.6
75	2.2	270	2.14	4.05	250	N/A	3.78	42.16	84.3
120	2.8	190	2.25	N/A	169	2.32	N/A	45.3	90.6
300	N/A	206	N/A	N/A	169	N/A	N/A	45.3	90.6
360	N/A	196	N/A	N/A	167	N/A	N/A	45.3	90.6
1020	3.31	220	2.72	N/A	174	2.93	N/A	45.3	90.6
1050	N/A	198	N/A	N/A	169	N/A	N/A	45.3	90.6
1080	N/A	194	N/A	N/A	166	N/A	N/A	45.3	90.6
1200	N\A	168	N\A	N/A	148	N/A	N/A	45.3	90.6
1320	3.58	166	3.23	N/A	146	3.29	N/A	45.3	90.6
1380	3.29	237	2.6	N/A	220	3.17	N/A	45.3	90.6
1440	N\A	251	N/A	N/A	227	N/A	N/A	45.3	90.6
1500	N\A	243	N/A	N/A	226	N/A	N/A	45.3	90.6
1560	N\A	246	N/A	N/A	225.5	N/A	N/A	45.3	90.6
1620	N\A	243	N/A	N/A	225	N/A	N/A	45.3	90.6
2520	N\A	138	N\A	N/A	120	N/A	N/A	45.3	90.6
2550	5.5	145	4.79	N/A	126.5	4.2	N/A	45.3	90.6
2580	4.43	136	4.15	N/A	126	4.22	N/A	45.3	90.6
2640	4.57	140	4.26	N/A	146	4.23	N/A	45.3	90.6
2670	N\A	124	N\A	N/A	125	N/A	N/A	45.3	90.6
2700	N\A	119	N\A	N/A	122	N/A	N/A	45.3	90.6
2760	5.59	114	5.26	N/A	112	5.35	N/A	45.3	90.6
2820	5.46	100	5.32	N/A	96	5.4	N/A	45.3	90.6
2850	N\A	114	N/A	N/A	114	N/A	N/A	45.3	90.6
2880	N\A	116	N/A	N/A	118	N/A	N/A	45.3	90.6
2910	N\A	114	N/A	N/A	117	N/A	N/A	45.3	90.6
2940	N\A	112	N/A	N/A	116	N/A	N/A	45.3	90.6

Flux Rates and Rejections for PES Tubular Membrane with Site A Wellhead Emulsion Feed

TIME (hr.)	TUBES 1,2 &3		TUBES 4.5 &6	
	FLUX RATE M3/M2 D	PERCENT REJECTION	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	12.57	9.17	11.45	5.24
0.5	12.25	N/A	10.88	N/A
0.75	12.01	8.79	10.84	4.14
1	11.53	N/A	10.68	N/A
1.25	10.88	2.73	10.08	N/A
2	7.66	19.64	6.81	17.14
5	8.30	N/A	6.81	N/A
6	7.90	N/A	6.73	N/A
17	8.87	17.82	7.01	11.48
17.5	7.98	N/A	6.81	N/A
18	7.82	N/A	6.69	N/A
20	6.77	N/A	5.96	N/A
22	6.69	9.78	5.88	8.10
23	9.55	20.97	8.87	3.65
24	10.12	N/A	9.15	N/A
25	9.79	N/A	9.11	N/A
26	9.91	N/A	9.09	N/A
27	9.79	N/A	9.07	N/A
42	5.56	N/A	4.84	N/A
42.5	5.84	12.91	5.10	23.64
43	5.48	6.32	5.08	4.74
44	5.64	6.78	5.88	7.44
44.5	5.00	N/A	5.04	N/A
45	4.80	N/A	4.92	N/A
46	4.59	5.90	4.51	4.29
47	4.03	2.56	3.87	1.10
47.5	4.59	N/A	4.59	N/A
48	4.67	N/A	4.76	N/A
48.5	4.59	N/A	4.72	N/A
49	4.51	N/A	4.67	N/A

FLUX DATA FROM TEST NUMBER A2

DATE : FEB. 27, 1986 MEMBRANE : PVDF FEED : Site A Wellhead Emulsion

TIME (min.)	FEED COND.	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (l)	% VOL. RED.
		PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. PERM. (l)		
15	2.46	320	1.9	4.81	327	1.83	4.9	9.71	19.42
30	n/a	254	N/A	3.82	257	N/A	3.86	17.39	34.78
45	2.41	247	1.94	3.71	251	2	3.76	24.86	49.72
60	N/A	225	N/A	3.38	230	N/A	3.45	31.69	63.38
75	2.5	222	1.94	3.34	223	2.32	3.345	38.375	76.75
90	N/A	200	N/A	3	206	N/A	3.09	44.465	88.93
93	2.79	210	2.12	0.63	203	2.27	0.61	45.705	91.41
120	N/A	191	N/A	N/A	196.5	N/A	N/A	45.7	91.4
180	N/A	192	N/A	N/A	194	N/A	N/A	45.7	91.4
240	2.68	194.5	2.27	N/A	196	2.29	N/A	45.7	91.4
1200	2.45	174	2.12	N/A	173	2.15	N/A	45.7	91.4
1260	N/A	168	N/A	N/A	168	N/A	N/A	45.7	91.4
1320	N/A	170	N/A	N/A	164	N/A	N/A	45.7	91.4
1380	N/A	164	N/A	N/A	164	N/A	N/A	45.7	91.4
1440	2.6	166	2.27	N/A	162	2.34	N/A	45.7	91.4
1500	N/A	162	N/A	N/A	162	N/A	N/A	45.7	91.4
1560	N/A	157	N/A	N/A	155	N/A	N/A	45.7	91.4
1620	N/A	164	N/A	N/A	162	N/A	N/A	45.7	91.4
2640	2.4	158	2.14	N/A	154	2.13	N/A	45.7	91.4
2700	N/A	156	N/A	N/A	158	N/A	N/A	45.7	91.4
2760	N/A	156	N/A	N/A	156	N/A	N/A	45.7	91.4
2820	N/A	156	N/A	N/A	158	N/A	N/A	45.7	91.4
4140	N/A	137	N/A	N/A	137	N/A	N/A	45.7	91.4
4320	2.43	132	2.16	N/A	132	2.16	N/A	45.7	91.4
5400	N/A	115	N/A	N/A	121	N/A	N/A	45.7	91.4
5580	2.5	108.5	2.17	N/A	115	2.19	N/A	45.7	91.4
5610	N/A	107.5	N/A	N/A	110	N/A	N/A	45.7	91.4
5715	N/A	124	N/A	N/A	136	N/A	N/A	45.7	91.4
5760	2.73	121	2.26	N/A	122	2.23	N/A	45.7	91.4
5820	2.55	113	2.13	N/A	111	2.15	N/A	45.7	91.4
5880	N/A	108	N/A	N/A	108	N/A	N/A	45.7	91.4
6000	2.57	115.5	2.15	N/A	115.5	2.1	N/A	45.7	91.4
6015	N/A	107.5	N/A	N/A	110.5	N/A	N/A	45.7	91.4
6075	N/A	96	N/A	N/A	98	N/A	N/A	45.7	91.4
6150	1.96	124	1.53	N/A	123	1.55	N/A	45.7	91.4

Flux Rates and Rejections for PVDF Tubular Membrane Test with Site A Wellhead Emulsion Feed

TIME (hr.)	TUBES 1, 2 & 3		TUBES 4, 5 & 6	
	FLUX RATE M3/M2 D	PERCENT REJECTION	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	12.90	22.76	13.18	25.61
0.5	10.24	N/A	10.36	N/A
0.75	9.95	19.50	10.12	17.01
1	9.07	N/A	9.27	N/A
1.25	8.95	22.40	8.99	7.20
1.5	8.06	N/A	8.30	N/A
1.55	8.46	24.01	8.18	18.64
2	7.70	N/A	7.92	N/A
3	7.74	N/A	7.82	N/A
4	7.84	15.30	7.90	14.55
20	7.01	13.47	6.97	12.24
21	6.77	N/A	6.77	N/A
22	6.85	N/A	6.61	N/A
23	6.61	N/A	6.61	N/A
24	6.69	12.69	6.53	10.00
25	6.53	N/A	6.53	N/A
26	6.33	N/A	6.25	N/A
27	6.61	N/A	6.53	N/A
44	6.37	10.83	6.21	11.25
45	6.29	N/A	6.37	N/A
46	6.29	N/A	6.29	N/A
47	6.29	N/A	6.37	N/A
69	5.52	N/A	5.52	N/A
72	5.32	11.11	5.32	11.11
90	4.63	N/A	4.88	N/A
93	4.37	13.20	4.63	12.40
93.5	4.33	N/A	4.43	N/A
95.25	5.00	N/A	5.48	N/A
96	4.88	17.22	4.92	18.32
97	4.55	16.47	4.47	15.69
98	4.35	N/A	4.35	N/A
100	4.65	16.34	4.65	18.29
100.25	4.33	N/A	4.45	N/A
101.25	3.87	N/A	3.95	N/A
102.5	5.00	21.94	4.96	20.92

FLUX DATA FROM TEST NUMBER A3

DATE: FEB. 4 1986 MEMBRANE : CHP-CA FEED : Site A Wellhead Emulsion

TIME (hrs.)	FEED COND.	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (l)	% VOL. RED.
		PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. PERM. (l)		
0.25	2.45	309	2.01	4.64	292	2.01	4.4	9.04	18
0.5	2.47	243	2	3.65	238	2.07	3.575	16.27	32.5
0.75	N/A	235	N/A	3.53	229	N/A	3.44	23.24	46.5
1	2.7	207	2.3	3.1	201	2.35	3.01	29.35	58.7
1.25	N/A	183	N/A	2.75	181	N/A	2.71	34.81	69.6
1.5	N/A	193	N/A	2.9	187	N/A	2.81	40.52	81
2.5	N/A	192	N/A	0	184	N/A	0	45	90
3.5	3.06	202	2.37	0	192	2.84	0	45	90
5	N/A	202	N/A	0	197	N/A	0	45	90
6.5	N/A	208	N/A	0	204	N/A	0	45	90
8	N/A	188	N/A	0	179	N/A	0	45	90
23	N/A	208	N/A	0	203	N/A	0	45	90
25	N/A	210	N/A	0	203	N/A	0	45	90
27	N/A	206	N/A	0	193	N/A	0	45	90
29	N/A	206	N/A	0	200	N/A	0	45	90
32.75	N/A	208	N/A	0	203	N/A	0	45	90
33	N/A	224	N/A	0	218	N/A	0	45	90
47.5	3.45	192	2.78	0	189	2.88	0	45	90
51.5	3.79	182	3.17	0	176	3.46	0	45	90
53.5	N/A	188	N/A	0	182	N/A	0	45	90
58.5	N/A	184	N/A	0	180	N/A	0	45	90
70	N/A	163	N/A	0	155	N/A	0	45	90
70.5	N/A	165	N/A	0	164	N/A	0	45	90
71	3.09	168	2.7	0	161	2.66	0	45	90
72	N/A	162	N/A	0	161	N/A	0	45	90
73	N/A	150	N/A	0	176	N/A	0	45	90
73.5	3.71	190	3.21	0	180	3.46	0	45	90
74	3.71	188	3.15	0	176	3.42	0	45	90
74.5	4.18	176	3.43	0	167	3.63	0	45	90
75	3.97	168	3.36	0	154	3.66	0	45	90
75.5	4.24	150	3.58	0	136	3.86	0	45	90
76	3.85	120	3.5	0	112	3.68	0	45	90
76.25	N/A	135	N/A	0	130	N/A	0	45	90
77.25	N/A	134	N/A	0	137	N/A	0	45	90
77.75	N/A	160	N/A	0	152	N/A	0	45	90
78.25	N/A	160	N/A	0	160	N/A	0	45	90
78.5	N/A	160	N/A	0	150	N/A	0	45	90

Flux Rates and Rejections for CHP-CA Tubular Membrane with Site A Wellhead Emulsion Feed

TIME (hours)	TUBES 1,2 & 3		TUBES 4,5 & 6	
	FLUX RATE M3/M2 D	PERCENT REJECTION	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	12.45	17.96	11.77	17.96
0.50	9.79	19.03	9.59	16.19
0.75	9.47	N/A	9.23	N/A
1.00	8.34	14.81	8.10	12.96
1.25	7.37	N/A	7.29	N/A
1.50	7.78	N/A	7.54	N/A
2.50	7.74	N/A	7.42	N/A
3.50	8.14	22.55	7.74	7.19
5.00	8.14	N/A	7.94	N/A
6.50	8.38	N/A	8.22	N/A
8.00	7.58	N/A	7.21	N/A
23.00	8.38	N/A	8.18	N/A
25.00	8.46	N/A	8.18	N/A
27.00	8.30	N/A	7.78	N/A
29.00	8.30	N/A	8.06	N/A
32.75	8.38	N/A	8.18	N/A
33.00	9.03	N/A	8.79	N/A
47.50	7.74	19.42	7.62	16.52
51.50	7.33	16.36	7.09	8.71
53.50	7.58	N/A	7.33	N/A
58.50	7.42	N/A	7.25	N/A
70.00	6.57	N/A	6.25	N/A
70.50	6.65	N/A	6.61	N/A
71.00	6.77	12.62	6.49	13.92
72.00	6.53	N/A	6.49	N/A
73	6.05	N/A	7.09	N/A
73.5	7.66	13.48	7.25	6.74
74	7.58	15.09	7.09	7.82
74.5	7.09	17.94	6.73	13.16
75	6.77	15.37	6.21	7.81
75.5	6.05	15.57	5.48	8.96
76	4.84	9.09	4.51	4.42
76.25	5.44	N/A	5.24	N/A
77.25	5.40	N/A	5.52	N/A
77.75	6.45	N/A	6.13	N/A
78.25	6.45	N/A	6.45	N/A
78.5	6.45	N/A	6.05	N/A

FLUX DATA FROM TEST NUMBER A4

DATE: March 11, 1986 MEMBRANE : CHP TFC FEED : Site A Wellhead Emulsion

		TUBES 1,2 & 3			TUBES 4,5, & 6				
TIME (HOURS)	FEED COND.	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	TOTAL PERM. VOL.	% VOL. RED.
0.25	2.27	119.30	1.47	1.79	109.30	1.51	1.64	3.43	6.60
0.50	N/A	121.30	N/A	1.82	113.00	N/A	1.70	6.95	13.37
0.75	N/A	115.00	N/A	1.73	107.30	N/A	1.16	10.29	19.79
1.00	2.34	113.30	1.62	1.70	106.00	1.67	1.59	13.58	26.12
1.25	N/A	122.00	N/A	1.83	114.60	N/A	1.72	17.13	32.94
1.50	2.48	114.70	1.71	1.72	107.70	1.76	1.62	20.47	39.37
1.75	N/A	114.86	N/A	1.72	108.70	N/A	1.63	23.82	45.81
2.00	2.54	116.00	1.76	1.74	109.30	1.79	1.64	27.20	52.31
2.25	N/A	116.00	N/A	1.75	110.70	N/A	1.66	30.61	58.87
2.50	N/A	118.70	N/A	1.78	112.70	N/A	1.69	34.08	65.54
2.75	N/A	115.30	N/A	1.73	109.30	N/A	1.64	37.45	72.02
3.00	N/A	116.00	N/A	1.74	110.70	N/A	1.66	40.85	78.56
3.25	3.22	104.70	2.19	1.57	100.00	2.23	1.50	43.92	84.46
3.75	N/A	121.50	N/A	1.90	117.50	N/A	1.84	47.66	91.65
4.25	N/A	119.00	N/A	N/A	124.00	N/A	N/A	47.66	91.65
14.75	3.34	122.00	2.32	N/A	116.00	2.39	N/A	47.66	91.65
20.75	N/A	126.00	N/A	N/A	120.00	N/A	N/A	47.66	91.65
22.75	N/A	124.00	N/A	N/A	121.00	N/A	N/A	47.66	91.65
37.75	3.95	126.00	2.85	N/A	120.00	2.85	N/A	47.66	91.65
44.75	N/A	128.00	N/A	N/A	124.00	N/A	N/A	47.66	91.65
63.00	3.48	124.00	2.56	N/A	117.00	2.59	N/A	47.66	91.65
67.00	3.70	120.00	2.76	N/A	114.00	2.80	N/A	47.66	91.65
71.00	N/A	121.00	N/A	N/A	115.00	N/A	N/A	47.66	91.65
89.00	3.53	128.00	2.48	N/A	122.00	2.60	N/A	47.66	91.65
91.00	N/A	126.00	N/A	N/A	120.00	N/A	N/A	47.66	91.65
115.00	3.25	128.00	2.35	N/A	121.00	2.37	N/A	47.66	91.65
134.00	N/A	127.50	N/A	N/A	121.00	N/A	N/A	47.66	91.65
144.00	N/A	126.00	N/A	N/A	118.00	N/A	N/A	47.66	91.65
159.00	3.55	125.00	2.69	N/A	117.00	2.67	N/A	47.66	91.65
167.00	3.59	124.00	2.62	N/A	116.00	2.66	N/A	47.66	91.65
183.00	3.15	124.00	2.37	N/A	114.00	2.42	N/A	47.66	91.65
188.00	3.15	128.00	2.28	N/A	121.00	2.35	N/A	47.66	91.65
190.00	3.36	136.00	2.45	N/A	128.00	2.49	N/A	47.66	91.65
192.50	3.46	131.00	2.4	N/A	122.00	2.47	N/A	47.66	91.65
207.00	3.44	134.00	2.5	N/A	126.00	2.56	N/A	47.66	91.65

Flux Rates and Rejections for CHP-TFC Tubular Membrane with Site A Wellhead Emulsion Feed

	TUBES 1,2 & 3		TUBES 4,5, & 6	
TIME (HOURS)	FLUX RATE M3/M2 D	PERCENT REJECTION	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	4.81	35.24	4.40	33.48
0.50	4.89	N/A	4.55	N/A
0.75	4.63	N/A	4.32	N/A
1.00	4.57	30.77	4.27	28.63
1.25	4.92	N/A	4.62	N/A
1.50	4.62	31.05	4.34	29.03
1.75	4.63	N/A	4.38	N/A
2.00	4.67	30.71	4.40	29.53
2.25	4.67	N/A	4.46	N/A
2.50	4.78	N/A	4.54	N/A
2.75	4.65	N/A	4.40	N/A
3.00	4.67	N/A	4.46	N/A
3.25	4.22	31.99	4.03	30.75
3.75	4.90	N/A	4.74	N/A
4.25	4.80	N/A	5.00	N/A
14.75	4.92	30.54	4.67	28.44
20.75	5.08	N/A	4.84	N/A
22.75	5.00	N/A	4.88	N/A
37.75	5.08	27.85	4.84	27.85
44.75	5.16	N/A	5.00	N/A
63.00	5.00	26.44	4.72	25.57
67.00	4.84	25.41	4.59	24.32
71.00	4.88	N/A	4.63	N/A
89.00	5.16	29.75	4.92	26.35
91.00	5.08	N/A	4.84	N/A
115.00	5.16	27.69	4.88	27.08
134.00	5.14	N/A	4.88	N/A
144.00	5.08	N/A	4.76	N/A
159.00	5.04	24.23	4.72	24.79
167.00	5.00	27.02	4.67	25.91
183.00	5.00	24.76	4.59	23.17
188.00	5.16	27.62	4.88	25.40
190.00	5.48	27.08	5.16	25.89
192.50	5.28	30.64	4.92	28.61
207.00	5.40	27.33	5.08	25.58

FLUX DATA FROM TEST NUMBER A5

DATE: March 20, 1986 MEMBRANE : HPC - 1076 FEED : Site A Wellhead Emulsion

		TUBES 1,2 & 3			TUBES 4,5 & 6				
TIME (hrs.)	FEED COND.	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. PERM. (l)	TOTAL PERM. VOL. (l)	% VOL. RED.
1.75	2.35	196	1.81	2.94	181.3	1.76	2.72	5.66	11.3
2	N/A	200	N/A	3	185.3	N/A	2.78	11.44	22.9
2.25	2.34	199.3	1.89	2.99	182.6	1.9	2.74	17.17	34.3
2.5	N/A	179.3	N/A	2.69	166.3	N/A	2.495	22.36	44.7
2.75	N/A	185.3	N/A	2.78	172	N/A	2.58	27.72	55.4
3	N/A	177.3	N/A	2.66	163.3	N/A	2.45	32.83	65.7
3.25	2.56	181.3	2.08	2.72	168.7	2.1	2.53	38.08	76.2
3.5	N/A	163.3	N/A	2.45	155.3	N/A	2.27	42.80	85.6
3.62	N/A	162.8	N/A	1.14	151.4	N/A	1.06	45.00	90.0
4.5	2.8	168.0	2.38	0	150.5	2.41	0	45	90
5.5	N/A	183.0	N/A	0	165.0	N/A	0	45	90
26	3.31	190.0	2.38	0	180.0	2.44	0	45	90
27	3.14	196.0	2.44	0	183.0	2.45	0	45	90
49	N/A	210.0	N/A	0	192.0	N/A	0	45	90
68	2.7	214.0	2.17	0	204.0	2.18	0	45	90
75	2.72	220.0	2.29	0	204.0	2.34	0	45	90
81	3.18	204.0	2.72	0	198.0	2.76	0	45	90
107	3.14	204.0	2.62	0	197.0	2.68	0	45	90
114	2.89	202.0	2.4	0	193.0	2.42	0	45	90
129	3.05	203.0	2.63	0	190.0	2.66	0	45	90
137	3.26	198.0	2.82	0	188.0	2.84	0	45	90
162	3.28	190.0	2.84	0	180.0	2.86	0	45	90
162.5	3.23	192.0	2.84	0	181.0	2.85	0	45	90
164	2.98	226.0	2.57	0	229.0	2.56	0	45	90
165	3	206.0	2.66	0	208.0	2.62	0	45	90
166	3.4	212.0	2.74	0	213.0	2.71	0	45	90

Flux Rates and Rejections for HPC Tubular Membrane
Site A with Wellhead Emulsion Feed

TIME (hours)	TUBES 1,2 & 3		TUBES 4,5 & 6	
	FLUX RATE M3/M2 D	PERCENT REJECTION	FLUX RATE M3/M2 D	PERCENT REJECTION
1.75	7.90	22.98	7.31	25.11
2	8.06	N/A	7.47	N/A
2.25	8.03	19.23	7.36	18.80
2.5	7.23	N/A	6.70	N/A
2.75	7.47	N/A	6.93	N/A
3	7.15	N/A	6.58	N/A
3.25	7.31	18.75	6.80	17.97
3.5	6.58	N/A	6.26	N/A
3.62	6.56	N/A	6.10	N/A
4.5	6.77	15.00	6.07	13.93
5.5	7.37	N/A	6.65	N/A
26	7.66	28.10	7.25	26.28
27	7.90	22.29	7.37	21.97
49	8.46	N/A	7.74	N/A
68	8.62	19.63	8.22	19.26
75	8.87	15.81	8.22	13.97
81	8.22	14.47	7.98	13.21
107	8.22	16.56	7.94	14.65
114	8.14	16.96	7.78	16.26
129	8.18	13.77	7.66	12.79
137	7.98	13.50	7.58	12.88
162	7.66	13.41	7.25	12.80
162.5	7.74	12.07	7.29	11.76
164	9.11	13.76	9.23	14.09
165	8.30	11.33	8.38	12.67
166	8.54	19.41	8.58	20.29

FLUX DATA FROM TEST NUMBER A6

DATE: APRIL 11, 1986 MEMBRANE : Polyolefin (PO) FEED : Site A Wellhead

TIME (hrs.)	FEED COND.	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	TOTAL PERM. VOL. (l)	% VOL. RED.
0.00	N/A	141.00	N/A	N/A	0.00	0.00
0.25	2.00	138.70	1.98	2.08	2.08	4.16
0.50	N/A	120.00	N/A	1.80	3.88	7.76
0.75	N/A	124.67	N/A	1.87	5.75	11.50
1.00	N/A	120.67	N/A	1.81	7.56	15.12
1.25	2.28	116.67	1.99	1.75	9.31	18.62
1.50	2.20	117.00	2.04	1.76	11.07	22.13
1.75	N/A	118.10	N/A	1.89	12.96	25.91
2.00	2.06	117.90	1.95	1.71	14.67	29.33
2.25	N/A	116.67	N/A	1.75	16.42	32.83
2.50	2.08	115.00	1.97	1.73	18.14	36.28
2.75	N/A	110.67	N/A	1.66	19.80	39.60
3.25	2.09	113.00	2.00	3.39	23.19	46.38
3.50	N/A	113.30	N/A	1.70	24.89	49.78
3.75	2.02	114.67	1.92	1.72	26.61	53.22
4.00	N/A	116.67	N/A	1.75	28.36	56.72
4.25	N/A	115.67	N/A	1.74	30.10	60.19
4.50	N/A	114.67	N/A	1.72	31.82	63.63
4.75	N/A	114.67	N/A	1.72	33.54	67.07
5.00	N/A	114.67	N/A	1.72	35.26	70.51
5.50	N/A	115.30	N/A	3.46	38.72	77.43
6.00	N/A	120.30	N/A	3.73	42.45	84.89
6.25	2.15	106.67	2.01	1.60	44.05	88.09
6.39	2.23	110.60	2.06	0.94	44.99	89.97
6.50	N/A	120.00	N/A	0.00	45.00	90.00
20.50	2.47	120.00	2.31	0.00	45.00	90.00
48.00	2.35	113.50	2.19	0.00	45.00	90.00
65.00	2.37	124.00	2.22	0.00	45.00	90.00
74.00	2.47	124.00	2.30	0.00	45.00	90.00
89.00	2.50	121.00	2.36	0.00	45.00	90.00
98.00	2.54	121.00	2.30	0.00	45.00	90.00
113.50	2.35	122.00	2.20	0.00	45.00	90.00
120.50	2.27	122.00	2.17	0.00	45.00	90.00
136.00	2.32	121.00	2.17	0.00	45.00	90.00
138.00	2.32	124.00	2.27	0.00	45.00	90.00
139.00	2.31	118.00	2.18	0.00	45.00	90.00
141.00	2.32	128.00	2.20	0.00	45.00	90.00
143.00	2.32	123.00	2.21	0.00	45.00	90.00
144.00	2.39	125.50	2.22	0.00	45.00	90.00
145.00	2.44	122.00	2.23	0.00	45.00	90.00
160.00	2.35	123.00	2.22	0.00	45.00	90.00
170.00	2.35	124.00	2.23	0.00	45.00	90.00

Flux Rates and Rejections for PO Tubular Membrane with Site A Wellhead Emulsion Feed

TIME (hours)	FLUX RATE M3/M2 D	PERCENT REJECTION
0.0	5.7	N/A
0.3	5.6	1.00
0.5	4.8	N/A
0.8	5.0	N/A
1.0	4.9	N/A
1.3	4.7	12.72
1.5	4.7	7.27
1.8	4.8	N/A
2.0	4.8	5.34
2.3	4.7	N/A
2.5	4.6	5.29
2.8	4.5	N/A
3.3	4.6	4.31
3.5	4.6	N/A
3.8	4.6	4.95
4.0	4.7	N/A
4.3	4.7	N/A
4.5	4.6	N/A
4.8	4.6	N/A
5.0	4.6	N/A
5.5	4.6	N/A
6.0	4.8	N/A
6.3	4.3	6.51
6.4	4.5	7.62
6.5	4.8	N/A
20.5	4.8	6.48
48.0	4.6	6.81
65.0	5.0	6.33
74.0	5.0	6.88
89.0	4.9	5.60
98.0	4.9	9.45
113.5	4.9	6.38
120.5	4.9	4.41
136.0	4.9	6.47
138.0	5.0	2.16
139.0	4.8	5.63
141.0	5.2	5.17
143.0	5.0	4.74
144.0	5.1	7.11
145.0	4.9	8.61
160.0	5.0	5.53
170.0	5.0	5.11

APPENDIX F

FLUX RATE DATA FOR TUBULAR AND SPIRAL TESTING WITH SITE "A" HTS SAMPLE

FLUX DATA FROM TEST NUMBER A7

DATE: APRIL 1, 1986 MEMBRANE : CHP-TFC/TUB. FEED : Site A HTS Water

TIME (hrs.)	FEED COND.	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (l)	% VOL. RED.
		PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	PERM. RATE (mls/min.)	PERM. COND.	VOL. PERM. (l)		
0.25	2.21	89.30	1.67	1.34	77.00	1.67	1.155	2.50	5.0
0.5	2.2	92.30	1.57	1.385	80.67	1.65	1.21	5.09	10.2
0.75	2.26	91.30	1.57	1.37	81.00	1.62	1.215	7.68	15.4
1	2.3	91.70	1.62	1.375	81.70	1.67	1.225	10.28	20.6
1.25	N/A	92.00	N/A	1.38	82.70	N/A	1.24	12.90	25.8
1.5	N/A	91.30	N/A	1.37	82.70	N/A	1.24	15.51	31.0
1.75	N/A	94.70	N/A	1.42	85.30	N/A	1.28	18.21	36.4
2	N/A	96.70	N/A	1.45	88.70	N/A	1.33	20.99	42.0
2.25	2.45	97.30	1.8	1.46	89.00	1.8	1.335	23.78	47.6
2.5	2.54	91.70	1.83	1.375	84.00	1.87	1.26	26.42	52.8
2.75	N/A	94.00	N/A	1.41	86.30	N/A	1.295	29.12	58.2
3	N/A	93.00	N/A	1.395	85.30	N/A	1.28	31.80	63.6
3.25	2.73	89.30	1.98	1.34	82.00	2.01	1.23	34.37	68.7
3.5	N/A	92.70	N/A	1.39	85.30	N/A	1.28	37.04	74.1
3.75	3.03	93.00	2.28	1.395	86.00	2.32	1.29	39.72	79.4
4	N/A	92.70	N/A	1.39	86.00	N/A	1.29	42.40	84.8
4.25	3.29	90.00	2.33	1.36	84.00	2.33	1.26	45.02	90.0
4.5	N/A	97.00	N/A	0	89.00	N/A	0	45	90
19	3.32	100.00	2.32	0	96.00	2.25	0	45	90
24	3.39	90.00	2.31	0	86.00	2.34	0	45	90
27	3.39	96.00	2.19	0	90.00	2.22	0	45	90
43	3.4	90.00	2.17	0	86.00	2.22	0	45	90
46	3.38	90.00	2.4	0	87.00	2.37	0	45	90
47.5	2.6	76.33	1.66	2.29	74.67	1.68	2.24	49.53	49.5
47.75	2.46	78.00	1.64	1.17	76.70	1.65	1.15	51.85	51.9
48	2.45	76.70	1.64	1.15	75.30	1.67	1.13	54.13	54.1
48.25	N/A	78.70	N/A	1.17	76.00	N/A	1.14	56.44	56.4
48.5	2.6	78.70	N/A	1.18	77.30	1.83	1.16	58.78	58.8
48.75	N/A	79.30	N/A	1.19	78.70	N/A	1.18	61.15	61.2
49	2.4	80.70	1.65	1.21	79.30	1.66	1.19	63.55	63.6
49.25	N/A	80.00	N/A	1.2	79.00	N/A	1.185	65.94	65.9
49.5	2.78	79.30	1.86	1.19	78.00	1.81	1.17	68.30	68.3
49.75	N/A	79.30	N/A	1.19	78.00	N/A	1.17	70.66	70.7
50.25	2.85	77.70	1.91	2.33	75.70	1.95	2.27	75.26	75.3
50.5	N/A	78.00	N/A	1.17	76.30	N/A	1.145	77.57	77.6
50.75	3.04	80.70	2.07	1.21	79.30	2.09	1.19	79.97	80.0
51	N/A	80.00	N/A	1.2	78.00	N/A	1.17	82.34	82.3
51.25	N/A	78.70	N/A	1.18	77.00	2.42	1.155	84.68	84.7
51.5	N/A	82.00	N/A	1.23	80.30	N/A	1.205	87.11	87.1
51.75	N/A	80.70	N/A	1.21	79.30	N/A	1.19	89.51	89.5
52	N/A	79.33	N/A	1.19	78.00	N/A	1.17	91.87	91.9
52.25	N/A	80.70	N/A	1.21	79.33	N/A	1.19	94.27	94.3
52.33	4.08	82.00	2.79	0.41	82.00	2.78	0.41	95.09	95.1
53	N/A	82.00	N/A	0	78.00	N/A	0	95.09	95.1
67	3.9	76.00	2.6	0	76.00	2.63	0	95.09	95.1
69	4.34	76.00	2.71	0	75.00	2.74	0	95.09	95.1
71	4.18	83.00	2.82	0	77.00	2.84	0	95.09	95.1
71.5	N/A	78.00	N/A	0	75.50	N/A	0	95.09	95.1
72	N/A	82.00	N/A	0	78.00	N/A	0	95.09	95.1
73	4.09	80.50	2.74	0	77.00	2.77	0	95.09	95.1
74	4.18	89.50	2.87	0	82.00	2.92	0	95.09	95.1
74.5	N/A	88.00	N/A	0	85.00	N/A	0	95.09	95.1
75	N/A	89.00	N/A	0	84.00	N/A	0	95.09	95.1

Flux Rates and Rejections for CHP-TFC Tubular Membrane with Site A HTS Water Feed

TIME (hours)	TUBES 1,2 & 3 FLUX RATE M3/M2 D	TUBES 1,2 & 3 PERCENT REJECTION	TUBES 4,5 & 6 FLUX RATE M3/M2 D	TUBES 4,5 & 6 PERCENT REJECTION
0.25	3.60	24.43	3.10	24.43
0.50	3.72	28.64	3.25	25.00
0.75	3.68	30.53	3.26	28.32
1.00	3.70	29.57	3.29	27.39
1.25	3.71	N/A	3.33	N/A
1.50	3.68	N/A	3.33	N/A
1.75	3.82	N/A	3.44	N/A
2.00	3.90	N/A	3.57	N/A
2.25	3.92	26.53	3.59	26.53
2.50	3.70	27.95	3.39	26.38
2.75	3.79	N/A	3.48	N/A
3.00	3.75	N/A	3.44	N/A
3.25	3.60	27.47	3.30	26.37
3.50	3.74	N/A	3.44	N/A
3.75	3.75	24.75	3.47	23.43
4.00	3.74	N/A	3.47	N/A
4.25	3.63	29.18	3.39	29.18
4.50	3.91	N/A	3.59	N/A
19.00	4.03	30.12	3.87	32.23
24.00	3.63	31.86	3.47	30.97
27.00	3.87	35.40	3.63	34.51
43.00	3.63	36.18	3.47	34.71
46.00	3.63	28.99	3.51	29.88
47.50	3.08	36.15	3.01	35.38
47.75	3.14	33.33	3.09	32.93
48.00	3.09	33.06	3.03	31.84
48.25	3.17	N/A	3.06	N/A
48.50	3.17	N/A	3.12	29.62
48.75	3.20	N/A	3.17	N/A
49.00	3.25	31.25	3.20	30.83
49.25	3.22	N/A	3.18	N/A
49.50	3.20	33.09	3.14	34.89
49.75	3.20	N/A	3.14	N/A
50.25	3.13	32.98	3.05	31.58
50.50	3.14	N/A	3.07	N/A
50.75	3.25	31.91	3.20	31.25
51.00	3.22	N/A	3.14	N/A
51.25	3.17	N/A	3.10	N/A
51.50	3.30	N/A	3.24	N/A
51.75	3.25	N/A	3.20	N/A
52.00	3.20	N/A	3.14	N/A
52.25	3.25	N/A	3.20	N/A
52.33	3.30	31.62	3.30	31.86
53.00	3.30	N/A	3.14	N/A
67.00	3.06	33.33	3.06	32.56
69.00	3.06	37.56	3.02	36.87
71.00	3.34	32.54	3.10	32.06
71.50	3.14	N/A	3.04	N/A
72.00	3.30	N/A	3.14	N/A
73.00	3.24	33.01	3.10	32.27
74.00	3.61	31.34	3.30	30.14
74.50	3.55	N/A	3.43	N/A
75.00	3.59	N/A	3.39	N/A

FLUX DATA FROM TEST NUMBER A8

DATE: APRIL 21, 1986 MEMBRANE : CHP-TFC/SPI. FEED : Site A HTS Water

TIME (hrs.)	FEED COND.	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	TOTAL PERM. (l)	% VOL. RED.
0.25	N/A	590.0	N/A	0	0.0	0.0%
0.50	N/A	515.0	N/A	0	0.0	0.0%
0.75	2.17	500.0	1.48	0	0.0	0.0%
0.83	N/A	508.0	N/A	2.54	2.5	5.1%
0.92	2.14	502.0	1.42	2.51	5.1	10.1%
1.00	N/A	458.0	N/A	2.29	7.3	14.7%
1.08	N/A	440.0	N/A	2.2	9.5	19.1%
1.17	N/A	443.0	N/A	2.215	11.8	23.5%
1.25	N/A	435.0	N/A	2.175	13.9	27.9%
1.29	N/A	424.0	N/A	1.06	15.0	30.0%
2.00	2.28	388.3	1.53	0	15.0	30.0%
3.00	N/A	375.0	N/A	0	15.0	30.0%
4.50	N/A	346.7	N/A	0	15.0	30.0%
5.00	N/A	330.0	N/A	0	15.0	30.0%
20.00	2.23	307.0	1.48	0	15.0	30.0%
21.00	N/A	305.0	N/A	0	15.0	30.0%
22.00	2.25	315.0	1.48	0	15.0	30.0%
23.00	N/A	320.0	N/A	0	15.0	30.0%
24.00	N/A	310.0	N/A	0	15.0	30.0%
25.00	N/A	310.0	N/A	0	15.0	30.0%
25.08	N/A	293.0	N/A	1.46	16.5	32.9%
25.17	N/A	292.0	N/A	1.46	17.9	35.8%
25.25	N/A	292.0	N/A	1.46	19.4	38.7%
25.33	2.36	284.0	1.57	1.42	20.8	41.6%
25.42	N/A	286.0	N/A	1.43	22.2	44.4%
25.50	N/A	290.0	N/A	1.45	23.7	47.3%
25.58	N/A	292.0	N/A	1.46	25.1	50.3%
25.66	2.51	286.0	1.7	1.43	26.6	53.1%
25.75	N/A	280.0	N/A	1.4	28.0	55.9%
25.83	N/A	280.0	N/A	1.4	29.4	58.7%
25.87	N/A	280.0	N/A	0.63	30.0	60.0%
27.00	2.63	300.0	1.79	0	30.0	60.0%
28.00	2.64	295.0	1.77	0	30.0	60.0%
29.00	2.65	265.0	1.8	0	30.0	60.0%
44.00	2.68	245.0	1.84	0	30.0	60.0%
45.00	N/A	245.0	N/A	0	30.0	60.0%
46.00	N/A	255.0	N/A	0	30.0	60.0%
47.00	N/A	245.0	N/A	0	30.0	60.0%
50.50	N/A	805.0	N/A	0	30.0	60.0%
51.00	2.62	810.0	1.87	0	30.0	60.0%
51.50	2.68	775.0	1.87	0	30.0	60.0%
52.00	2.73	740.0	2.01	0	30.0	60.0%
53.00	2.73	750.0	2.01	0	30.0	60.0%
54.00	2.73	700.0	1.97	0	30.0	60.0%
69.00	2.73	530.0	1.86	0	30.0	60.0%
70.00	2.63	525.0	1.83	0	30.0	60.0%
73.00	2.69	925.0	2.03	0	30.0	60.0%
74.00	2.72	740.0	1.93	0	30.0	60.0%
75.00	2.72	700.0	1.93	0	30.0	60.0%
76.00	2.73	630.0	1.94	0	30.0	60.0%
94.00	2.64	540.0	1.84	0	30.0	60.0%
95.00	2.67	540.0	1.84	0	30.0	60.0%
96.00	2.66	1480.0	2.12	0	30.0	60.0%
97.00	N/A	980.0	N/A	0	30.0	60.0%
98.00	N/A	890.0	N/A	0	30.0	60.0%
99.00	N/A	880.0	N/A	0	30.0	60.0%
100.00	2.79	875.0	2.04	0	30.0	60.0%

Flux Rates and Rejections for CHP-TFC Spiral Membrane with Site A HTS Water Feed

TIME (hours)	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	2.11	N/A
0.50	1.84	N/A
0.75	1.79	31.8
0.83	1.81	N/A
0.92	1.79	33.6
1.00	1.64	N/A
1.08	1.57	N/A
1.17	1.58	N/A
1.25	1.55	N/A
1.29	1.51	N/A
2.00	1.39	32.9
3.00	1.34	N/A
4.50	1.24	N/A
5.00	1.18	N/A
20.00	1.10	33.6
21.00	1.09	N/A
22.00	1.12	34.2
23.00	1.14	N/A
24.00	1.11	N/A
25.00	1.11	N/A
25.08	1.05	N/A
25.17	1.04	N/A
25.25	1.04	N/A
25.33	1.01	33.5
25.42	1.02	N/A
25.50	1.04	N/A
25.58	1.04	N/A
25.66	1.02	32.3
25.75	1.00	N/A
25.83	1.00	N/A
25.87	1.00	N/A
27.00	1.07	31.9
28.00	1.05	33.0
29.00	0.95	32.1
44.00	0.87	31.3
45.00	0.87	N/A
46.00	0.91	N/A
47.00	0.87	N/A
50.50	2.87	N/A
51.00	2.89	28.6
51.50	2.77	30.2
52.00	2.64	26.4
53.00	2.68	26.4
54.00	2.50	27.8
69.00	1.89	31.9
70.00	1.87	30.4
73.00	3.30	24.5
74.00	2.64	29.0
75.00	2.50	29.0
76.00	2.25	28.9
94.00	1.93	30.3
95.00	1.93	31.1
96.00	5.28	20.3
97.00	3.50	N/A
98.00	3.18	N/A
99.00	3.14	N/A
100.00	3.12	26.9

FLUX DATA FROM TEST NUMBER A9

DATE: APRIL 30, 1986 MEMBRANE : CHP-TFC/SPI. FEED : Site A HTS Perm

TIME (hrs.)	FEED COND.	PERM. RATE (mls/min.)	PERM. COND.	VOL. OF PERM. (l)	TOTAL PERM. (l)	% VOL. RED.
0.25	N/A	1710.0	N/A	0	0.0	0.0%
0.50	N/A	1560.0	N/A	0	0.0	0.0%
0.75	N/A	1540.0	N/A	0	0.0	0.0%
1.00	N/A	1660.0	N/A	8.08	8.1	16.2%
1.08	N/A	1620.0	N/A	8.09	16.2	32.3%
1.17	N/A	1620.0	N/A	7.9	24.1	48.1%
1.25	2.05	1580.0	1.84	8.09	32.2	64.3%
1.33	N/A	1620.0	N/A	12.83	45.0	90.0%
2.00	N/A	1600.0	N/A	0	45.0	90.0%
3.00	2.14	1550.0	1.95	0	45.0	90.0%
4.00	N/A	1500.0	N/A	0	45.0	90.0%
5.00	N/A	1500.0	N/A	0	45.0	90.0%
20.00	2.02	1375.0	1.88	0	45.0	90.0%
22.00	N/A	1350.0	N/A	0	45.0	90.0%
23.00	N/A	1350.0	N/A	0	45.0	90.0%
24.00	2.11	1320.0	1.83	0	45.0	90.0%
25.00	2.04	2800.0	1.91	0	45.0	90.0%
25.25	N/A	2650.0	N/A	0	45.0	90.0%
28.00	N/A	2750.0	N/A	0	45.0	90.0%
30.00	2.01	2730.0	1.96	0	45.0	90.0%
45.00	2.01	2350.0	1.9	0	45.0	90.0%
46.00	N/A	2300.0	N/A	0	45.0	90.0%
48.00	1.86	2700.0	1.61	0	45.0	90.0%
50.00	N/A	2700.0	N/A	0	45.0	90.0%
54.00	1.98	2500.0	1.95	0	45.0	90.0%
72.00	2.02	2000.0	1.96	0	45.0	90.0%
73.00	N/A	2000.0	N/A	0	45.0	90.0%
74.00	1.95	1950.0	1.89	0	45.0	90.0%
76.00	1.88	2000	1.81	0	45.0	90.0%
77.00	N/A	2200	N/A	0	45.0	90.0%
78.00	1.8	2250	1.76	0	45.0	90.0%
94.00	1.95	2000	1.9	0	45.0	90.0%
95.00	1.91	1950	1.83	0	45.0	90.0%
96.00	1.88	1950	1.87	0	45.0	90.0%
97.00	1.94	1950	1.9	0	45.0	90.0%
98.00	N/A	1950	N/A	0	45.0	90.0%
99.00	N/A	1900	N/A	0	45.0	90.0%
100.00	1.88	1900	1.86	0	45.0	90.0%

Flux Rates and Rejections for CHP-TFC Spiral Membrane with Site A HTS Permeate Feed

TIME (hours)	FLUX RATE M3/M2 D	PERCENT REJECTION
0.25	6.10	N/A
0.50	5.57	N/A
0.75	5.50	N/A
1.00	5.93	N/A
1.08	5.78	N/A
1.17	5.78	N/A
1.25	5.64	10.2
1.33	5.78	N/A
2.00	5.71	N/A
3.00	5.53	8.9
4.00	5.36	N/A
5.00	5.36	N/A
20.00	4.91	6.9
22.00	4.82	N/A
23.00	4.82	N/A
24.00	4.71	13.3
25.00	10.00	6.4
25.25	9.46	N/A
28.00	9.82	N/A
30.00	9.75	2.5
45.00	8.39	5.5
46.00	8.21	N/A
48.00	9.64	13.4
50.00	9.64	N/A
54.00	8.93	1.5
72.00	7.14	3.0
73.00	7.14	N/A
74.00	6.96	3.1
76.00	7.14	3.7
77.00	7.85	N/A
78.00	8.03	2.2
94.00	7.14	2.6
95.00	6.96	4.2
96.00	6.96	0.5
97.00	6.96	2.1
98.00	6.96	N/A
99.00	6.78	N/A
100.00	6.78	1.1

APPENDIX G

FLUX DATA FOR LONG TERM TESTING WITH DIFFERENT EMULSIONS

FLUX RATES AND REJECTIONS FOR TEST #4 SITE D, Skim Tank WITH CHP - TFC / PSC - C MEMBRANES

TIME (hours)	CHP - TFC		PSC - C	
	FLUX RATE m3/m2/D	PERCENT REJECTION	FLUX RATE m3/m2/D	PERCENT REJECTION
0.25	2.14	N/A	6.42	N/A
0.50	2.28	7.48	6.38	3.95
0.75	2.31	N/A	6.05	N/A
1.00	2.22	4.96	5.65	1.45
1.25	2.14	N/A	5.09	N/A
1.50	2.26	5.80	5.43	2.20
1.75	2.12	N/A	5.05	N/A
2.00	2.15	5.18	5.03	2.48
2.33	2.02	N/A	4.67	N/A
2.50	2.10	5.08	4.88	1.63
2.75	1.97	N/A	4.46	N/A
3.00	1.88	7.75	4.22	5.04
3.25	1.93	N/A	4.35	N/A
3.50	1.99	6.16	4.42	4.57
3.75	2.00	N/A	4.35	N/A
4.00	2.10	5.31	4.57	2.36
4.25	2.15	N/A	4.62	N/A
4.50	2.22	9.55	4.73	1.69
4.75	2.35	N/A	4.76	N/A
5.00	2.34	3.87	4.89	0.81
19.75	2.34	3.17	4.41	0.99
20.00	2.64	N/A	4.88	N/A
20.25	2.67	6.38	4.93	3.09
20.50	2.65	N/A	4.87	N/A
20.75	2.59	3.29	4.76	1.36
21.00	2.62	N/A	4.81	N/A
21.25	2.66	3.87	4.84	2.03
21.50	2.67	N/A	4.88	N/A
21.75	2.69	4.45	4.89	0.00
22.00	2.69	N/A	4.86	N/A
22.25	2.53	5.21	4.67	3.81
22.50	2.63	N/A	4.78	N/A
22.75	2.65	3.65	4.74	1.83
23.00	2.62	N/A	4.73	N/A
43.75	2.50	5.70	4.43	3.04
69.50	2.74	5.77	4.80	1.05
91.25	2.78	4.65	4.55	1.03
93.00	2.74	4.16	4.51	1.21
96.25	2.94	4.03	4.51	0.00
100.00	2.70	3.02	4.47	2.52
115.50	2.74	4.00	4.51	1.33
118.25	2.78	2.99	4.43	1.66
120.50	2.78	5.77	4.47	2.81
123.00	2.82	5.77	4.55	2.88
140.00	2.82	4.55	4.76	1.95
144.00	2.74	3.06	4.47	1.61

FLUX RATES AND REJECTIONS FOR TEST #4 SITE D, Skim Tank
CHP - TFC / PSC - C MEMBRANES

TIME (hours)	CHP - TFC		PSC - C	
	FLUX RATE m3/m2/D	PERCENT REJECTION	FLUX RATE m3/m2/D	PERCENT REJECTION
146.00	2.74	4.14	4.35	2.15
163.50	2.70	3.52	4.03	1.22
165.75	2.74	4.33	3.99	2.01
168.00	1.93	2.37	2.78	1.11
171.00	1.93	5.49	2.78	3.18
190.25	2.34	3.80	3.16	2.92
214.50	2.26	4.05	3.14	2.31
235.25	1.97	3.81	2.78	2.82
237.75	2.26	4.07	3.14	2.87
240.00	2.10	5.24	2.98	5.09
243.25	2.02	4.56	5.48	2.58
243.50	2.14	N/A	5.24	N/A
243.75	2.10	N/A	4.92	N/A
267.75	2.62	4.69	5.20	1.25

SALT FLUX DATA FROM TEST #4 SITE D, Skim Tank

DATE: AUG. 1, 1986

MEMBRANE:CHP - TFC / PSC - C

RAW DATA

TIME (MIN.)	FEED COND	CHP - TFC		PSC - C		CHP - TFC		PSC - C		CHP - TFC		PSC - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
30	47.8	6	44.5	18	46.7	4.5	44.5	11	45.4	2.5	44.3	8.5	45.7
60	49.3	4.5	46.6	16.5	48.4	4	46.6	10	47.9	2.5	46.1	7.5	47.9

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	CHP - TFC		PSC - C		CHP - TFC		PSC - C		CHP - TFC		PSC - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
30	0.7	6.9	2.2	2.3	0.5	6.9	1.3	5.0	0.3	7.3	1.0	4.4
60	0.5	5.5	2.0	1.8	0.5	5.5	1.2	2.8	0.3	6.5	0.9	2.8

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 689 kPa

TEMP.: 25 °C

NaCl CONC.: 35,000 ppm

FLUX DATA FROM TEST #5 SITE E, Skim Tank

DATE: AUG. 28, 1986 MEMBRANE: CHP - TFC / PSC - C

TIME (hrs.)	FEED COND. (umho)	CHP - TFC PERM. RATE (ml./min.)	CHP - TFC PERM. COND. (umho)	PSC - C PERM. RATE (ml./min.)	PSC - C PERM. COND. (umho)	TOTAL PERM. VOL. (Litres)	% VOL. RED.
0.25	9.31	55.3	8.66	101.3	8.82	2.35	2.35
0.50	N/A	53.3	N/A	80.7	N/A	4.36	4.36
1.00	N/A	53.3	N/A	75.0	N/A	8.21	8.21
1.50	9.52	51.5	8.14	68.0	7.93	11.79	11.79
2.00	N/A	51.7	N/A	66.7	N/A	15.35	15.35
2.50	10.00	48.0	8.56	62.7	8.30	18.67	18.67
16.00	N/A	25.7	N/A	38.3	N/A	20.59	20.59
16.50	9.71	27.3	8.38	41.0	8.30	22.64	22.64
17.00	N/A	26.3	N/A	39.5	N/A	24.62	24.62
17.50	9.83	26.7	8.37	40.0	8.34	26.62	26.62
18.00	N/A	25.3	N/A	38.3	N/A	30.44	30.44
19.00	10.09	25.7	8.53	38.7	8.49	34.30	34.30
20.00	N/A	25.6	N/A	39.0	N/A	38.18	38.18
21.50	N/A	24.6	N/A	40.0	N/A	43.75	43.75
22.00	11.45	24.3	9.67	37.0	9.64	45.59	45.59
23.00	N/A	24.2	N/A	37.3	N/A	49.28	49.28
24.00	11.83	22.5	10.69	35.0	10.22	52.86	52.86
44.00	12.36	22.5	10.30	35.0	10.18	N/A	N/A
70.00	11.38	21.5	10.12	34.0	10.40	N/A	N/A
93.50	11.04	19.0	9.90	32.0	9.90	N/A	N/A
111.00	10.66	19.0	9.53	30.0	9.47	N/A	N/A
114.00	N/A	21.0	N/A	33.0	N/A	N/A	N/A
114.50	10.67	18.3	9.47	29.3	9.46	54.29	54.29
115.00	10.45	18.3	9.28	29.3	9.34	55.72	55.72
116.00	10.88	18.3	9.46	29.6	9.40	58.59	58.59
116.50	10.80	19.7	9.55	31.7	9.49	60.13	60.13
117.00	10.95	19.7	9.54	31.3	9.35	61.66	61.66
117.50	11.01	18.7	9.44	29.8	9.67	63.12	63.12
118.00	11.42	17.8	9.90	28.7	10.01	64.52	64.52
118.50	11.24	17.8	9.88	28.7	9.99	65.92	65.92
119.00	11.33	17.7	9.94	28.5	9.99	67.30	67.30
119.50	11.34	18.3	9.88	29.8	10.00	68.74	68.74
120.00	11.34	18.5	9.97	30.0	10.01	70.20	70.20
136.00	N/A	18.0	N/A	29.0	N/A	N/A	N/A
137.00	11.54	17.3	10.08	25.3	10.15	72.76	72.76
138.00	11.81	20.0	10.11	33.0	10.21	75.94	75.94
139.00	12.07	18.3	10.46	30.7	10.55	78.88	78.88
140.00	12.85	16.5	11.17	27.5	11.25	81.52	81.52
142.50	13.13	37.2	11.75	60.8	12.06	84.46	84.46
143.00	N/A	26.0	N/A	47.5	N/A	N/A	N/A
143.25	N/A	22.0	N/A	37.0	N/A	N/A	N/A
143.50	12.86	N/A	12.24	N/A	12.00	N/A	N/A
143.75	N/A	23.0	N/A	43.5	N/A	N/A	N/A
144.00	N/A	24.0	N/A	48.0	N/A	N/A	N/A
160.00	N/A	14.0	N/A	28.0	N/A	N/A	N/A
161.00	12.7	19.0	11.72	33.0	11.49	N/A	N/A
162.00	N/A	16.5	N/A	32.0	N/A	N/A	N/A
163.00	12.75	16.5	11.67	32.0	11.61	N/A	N/A
164.00	N/A	16.0	N/A	32.5	N/A	N/A	N/A
165.00	12.8	15.0	11.71	29.0	11.51	N/A	N/A
166.00	N/A	15.0	N/A	29.5	N/A	N/A	N/A
167.00	12.69	15.0	11.69	27.0	11.54	N/A	N/A

FLUX RATES AND REJECTIONS FOR TEST #5 SITE E, Skim Tank

WITH CHP - TFC / PSC - C MEMBRANES

TIME (hours)	CHP - TFC		PSC - C	
	FLUX RATE m3/m2/D	PERCENT REJECTION	FLUX RATE m3/m2/D	PERCENT REJECTION
0.25	3.3	6.98	4.1	5.26
0.50	3.2	N/A	3.2	N/A
1.00	3.2	N/A	3.0	N/A
1.50	3.1	14.50	2.7	16.70
2.00	3.1	N/A	2.7	N/A
2.50	2.9	14.40	2.5	17.00
16.00	1.5	N/A	1.5	N/A
16.50	1.6	13.70	1.6	14.52
17.00	1.6	N/A	1.6	N/A
17.50	1.6	14.85	1.6	15.16
18.00	1.5	N/A	1.5	N/A
19.00	1.5	15.46	1.5	15.86
20.00	1.5	N/A	1.6	N/A
21.50	1.5	N/A	1.6	N/A
22.00	1.5	15.55	1.5	15.81
23.00	1.5	N/A	1.5	N/A
24.00	1.4	9.64	1.4	13.61
44.00	1.4	16.67	1.4	17.64
70.00	1.3	11.07	1.4	8.61
93.50	1.1	10.33	1.3	10.33
111.00	1.1	10.60	1.2	11.16
114.00	1.3	N/A	1.3	N/A
114.50	1.1	11.25	1.2	11.34
115.00	1.1	11.20	1.2	10.62
116.00	1.1	13.05	1.2	13.60
116.50	1.2	11.57	1.3	12.13
117.00	1.2	12.88	1.3	14.61
117.50	1.1	14.26	1.2	12.17
118.00	1.1	13.31	1.1	12.35
118.50	1.1	12.10	1.1	11.12
119.00	1.1	12.27	1.1	11.83
119.50	1.1	12.87	1.2	11.82
120.00	1.1	12.08	1.2	11.73
136.00	1.1	N/A	1.2	N/A
137.00	1.0	12.65	1.0	12.05
138.00	1.2	14.39	1.3	13.55
139.00	1.1	13.34	1.2	12.59
140.00	1.0	13.07	1.1	12.45
142.50	2.2	10.51	2.4	8.15
143.00	1.6	N/A	1.9	N/A
143.25	1.3	N/A	1.5	N/A
143.50	1.4	4.82	1.6	6.69
143.75	1.4	N/A	1.7	N/A
144.00	1.4	N/A	1.9	N/A
160.00	0.8	N/A	1.1	N/A
161.00	1.1	7.72	1.3	9.53
162.00	1.0	N/A	1.3	N/A
163.00	1.0	8.47	1.3	8.94
164.00	1.0	N/A	1.3	N/A
165.00	0.9	8.52	1.2	10.08
166.00	0.9	N/A	1.2	N/A
167.00	0.9	7.88	1.1	9.06

SALT FLUX DATA FROM TEST #5 SITE E, Skim Tank

DATE: AUG. 28, 1986

MEMBRANE:CHP - TFC / PSC - C

RAW DATA

TIME (MIN.)	FEED COND	CHP - TFC		PSC - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
30	47.14	16	43.9	52	45.22
60	48.92	17.5	44.69	50	45.54

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	CHP - TFC		PSC - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
30	0.6	6.9	2.1	4.1
60	0.7	8.6	2.0	6.9

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 689 kPa

TEMP.: 25 °C

NaCl CONC.: 35,000 ppm

FLUX DATA FROM TEST #6 SITE F, FWKO

DATE: SEPT. 9, 1986 MEMBRANE :PSC - C

TIME (hrs.)	FEED COND. (umho)	TUBES 1,3 & 5 PERM. RATE (ml./min.)	TUBES 1,3 & 5 PERM. COND. (umho)	TUBES 1,3 & 5 VOL. OF PERM. (Litres)	TUBES 2,4 & 6 PERM. RATE (ml./min.)	TUBES 2,4 & 6 PERM. COND. (umho)	TUBES 2,4 & 6 VOL. PERM. (Litres)	TOTAL PERM. VOL. (Litres)	% VOL. RED.
0.17	21.1	260.0	20.8	2.60	335.0	20.7	3.35	5.95	5.95
0.33	N/A	204.0	N/A	2.04	261.0	N/A	2.61	10.60	10.60
0.50	N/A	178.0	N/A	1.78	225.0	N/A	2.25	14.63	14.63
0.75	N/A	160.0	N/A	2.40	200.0	N/A	3.00	20.03	20.03
1.00	21.4	150.0	20.6	2.25	185.0	20.5	2.77	25.05	25.05
1.25	N/A	144.0	N/A	2.16	175.0	N/A	2.63	29.84	29.84
1.50	N/A	131.0	N/A	1.97	160.0	N/A	2.40	34.21	34.21
1.75	N/A	125.0	N/A	1.88	153.0	N/A	2.29	38.38	38.38
2.00	21.4	124.0	20.5	1.86	150.0	20.4	2.25	42.49	42.49
2.25	N/A	119.0	N/A	1.79	144.0	N/A	2.16	46.44	46.44
2.50	N/A	117.0	N/A	1.75	141.0	N/A	2.11	50.30	50.30
2.75	N/A	116.0	N/A	1.74	140.0	N/A	2.10	54.14	54.14
3.00	21.3	112.0	20.5	1.68	132.0	20.6	1.98	57.80	57.80
3.25	N/A	113.0	N/A	1.69	133.0	N/A	2.00	61.49	61.49
19.25	21.1	59.3	19.6	0.89	65.3	20.3	0.98	63.36	63.36
19.50	N/A	59.3	N/A	0.89	64.0	N/A	0.96	65.21	65.21
20.00	N/A	49.3	N/A	1.48	53.7	N/A	1.61	68.30	68.30
20.50	N/A	51.0	N/A	1.53	55.3	N/A	1.66	71.49	71.49
21.00	21.0	52.0	20.1	1.56	56.3	20.2	1.69	74.74	74.74
21.50	N/A	51.3	N/A	1.54	55.3	N/A	1.66	77.94	77.94
22.00	21.2	50.3	20.3	1.51	54.3	20.5	1.63	81.08	81.08
22.25	N/A	51.3	N/A	0.77	54.7	N/A	0.82	82.67	82.67
23.25	21.8	51.3	20.5	3.09	55.0	20.5	3.30	89.06	89.06
24.50	21.8	49.5	20.4	0.00	52.5	20.8	0.00	0.00	90.00
25.50	22.3	48.0	20.0	0.00	51.5	20.4	0.00	0.00	90.00
26.50	22.0	47.5	21.0	0.00	52.0	21.2	0.00	0.00	90.00
27.00	22.1	47.0	21.0	0.00	50.0	21.2	0.00	0.00	90.00
43.50	22.0	51.0	21.2	0.00	52.0	21.4	0.00	0.00	90.00
48.50	23.0	49.0	22.2	0.00	52.0	21.8	0.00	0.00	90.00
67.00	22.8	41.3	22.1	0.00	46.5	22.2	0.00	0.00	90.00
69.00	22.9	45.0	22.2	0.00	47.0	22.3	0.00	0.00	90.00
71.00	24.8	136.0	24.1	0.00	157.0	24.3	0.00	0.00	90.00
73.00	24.3	118.0	23.7	0.00	137.0	23.9	0.00	0.00	90.00
93.00	23.4	95.0	23.0	0.00	115.0	23.2	0.00	0.00	90.00
117.00	24.6	87.0	23.8	0.00	104.0	23.8	0.00	0.00	90.00
137.00	25.1	84.0	24.6	0.00	95.5	24.6	0.00	0.00	90.00
148.00	23.9	76.5	23.8	0.00	88.5	23.8	0.00	0.00	90.00
161.00	23.8	73.0	23.5	0.00	82.0	23.5	0.00	0.00	90.00
164.00	N/A	70.0	N/A	0.00	78.0	N/A	0.00	0.00	90.00
166.00	26.5	79.0	26.7	0.00	91.0	26.6	0.00	0.00	90.00
169.00	26.4	73.0	25.6	0.00	79.0	25.8	0.00	0.00	90.00

FLUX RATES AND REJECTIONS FOR TEST #6 SITE F, FWKO
PSC - C MEMBRANES

TIME (hours)	TUBES 1,3,5 FLUX RATE m3/m2/D	TUBES 1,3,5 PERCENT REJECTION	TUBES 2,4,6 FLUX RATE m3/m2/D	TUBES 2,4,6 PERCENT REJECTION
0.17	10.5	1.71	13.5	2.04
0.33	8.2	N/A	10.5	N/A
0.50	7.2	N/A	9.1	N/A
0.75	6.4	N/A	8.1	N/A
1.00	6.0	3.69	7.5	4.30
1.25	5.8	N/A	7.1	N/A
1.50	5.3	N/A	6.4	N/A
1.75	5.0	N/A	6.2	N/A
2.00	5.0	4.35	6.0	4.91
2.25	4.8	N/A	5.8	N/A
2.50	4.7	N/A	5.7	N/A
2.75	4.7	N/A	5.6	N/A
3.00	4.5	3.80	5.3	3.33
3.25	4.6	N/A	5.4	N/A
19.25	2.4	6.97	2.6	3.61
19.50	2.4	N/A	2.6	N/A
20.00	2.0	N/A	2.2	N/A
20.50	2.1	N/A	2.2	N/A
21.00	2.1	4.61	2.3	3.80
21.50	2.1	N/A	2.2	N/A
22.00	2.0	4.52	2.2	3.44
22.25	2.1	N/A	2.2	N/A
23.25	2.1	6.01	2.2	6.01
24.50	2.0	6.46	2.1	4.72
25.50	1.9	10.38	2.1	8.68
26.50	1.9	4.81	2.1	3.86
27.00	1.9	5.29	2.0	4.34
43.50	2.1	3.86	2.1	2.82
48.50	2.0	3.22	2.1	5.09
67.00	1.7	2.81	1.9	2.37
69.00	1.8	2.84	1.9	2.36
71.00	5.5	2.99	6.3	2.14
73.00	4.8	2.23	5.5	1.32
93.00	3.8	1.79	4.6	0.90
117.00	3.5	2.97	4.2	2.97
137.00	3.4	2.11	3.8	2.11
148.00	3.1	0.46	3.6	0.46
161.00	2.9	1.38	3.3	1.34
164.00	2.8	N/A	3.1	N/A
166.00	3.2	0.00	3.7	0.00
169.00	2.9	2.99	3.2	2.43

FLUX DATA FROM TEST #7 SITE G, FWKO & HTS

DATE: SEPT. 24, 1986 MEMBRANE : PSC - C

TIME (hrs.)	FEED COND. (umho)	TUBES 1,3 & 5 PERM. RATE (ml./min.)	PERM. COND. (umho)	VOL. OF PERM. (Litres)	TUBES 2,4 & 6 PERM. RATE (ml./min.)	PERM. COND. (umho)	VOL. OF PERM. (Litres)	TOTAL PERM. VOL. (Litres)	% VOL. RED.
0.25	3.1	66.7	2.7	1.00	61.3	N/A	0.92	1.92	1.92
0.57	N/A	63.3	N/A	0.95	57.3	N/A	0.86	3.73	3.73
0.75	N/A	64.0	N/A	0.96	56.7	N/A	0.85	5.54	5.54
1.00	N/A	56.0	N/A	0.84	50.7	N/A	0.76	7.14	7.14
1.50	3.3	58.3	2.1	1.75	52.3	2.1	1.57	10.46	10.46
2.00	N/A	54.7	N/A	1.64	48.7	N/A	1.46	13.56	13.56
2.50	N/A	52.7	N/A	1.57	46.7	N/A	1.40	16.53	16.53
3.00	N/A	53.0	N/A	1.59	46.7	N/A	1.40	19.52	19.52
4.00	N/A	51.7	N/A	3.10	45.7	N/A	2.74	25.36	25.36
4.50	N/A	50.8	N/A	1.52	45.0	N/A	1.35	28.23	28.23
5.00	3.6	50.0	2.3	1.50	44.2	2.3	1.33	31.06	31.06
6.00	N/A	49.3	N/A	2.96	44.0	N/A	2.64	36.66	36.66
20.50	N/A	53.7	N/A	1.61	48.7	N/A	1.46	39.73	39.73
21.00	N/A	52.0	N/A	1.56	46.7	N/A	1.40	42.69	42.69
22.00	N/A	52.0	N/A	3.12	46.7	N/A	2.80	48.61	48.61
23.00	N/A	49.0	N/A	2.94	43.3	N/A	2.63	54.18	54.18
24.00	3.9	51.2	2.5	3.07	43.8	2.4	2.74	59.99	59.99
25.00	N/A	53.5	N/A	3.21	48.0	N/A	2.88	66.08	66.08
26.00	N/A	54.0	N/A	3.24	48.8	N/A	2.93	72.25	72.25
27.00	4.1	52.8	2.6	3.17	48.0	2.5	2.88	78.30	78.30
28.00	N/A	49.5	N/A	2.97	44.7	N/A	2.68	83.95	83.95
29.00	5.2	60.8	3.0	3.65	49.0	2.9	3.30	90.90	90.90
45.00	N/A	51.0	N/A	0.00	49.0	N/A	0.00	90.90	90.90
48.00	N/A	53.0	N/A	0.00	50.0	N/A	0.00	0.00	90.00
54.00	N/A	57.0	N/A	0.00	54.0	N/A	0.00	0.00	90.00
70.00	N/A	52.5	N/A	0.00	51.0	N/A	0.00	0.00	90.00
96.00	N/A	57.0	N/A	0.00	55.0	N/A	0.00	0.00	90.00
116.00	7.9	50.0	5.3	0.00	52.0	5.0	0.00	0.00	90.00
126.00	7.8	53.0	5.2	0.00	52.5	5.0	0.00	0.00	90.00
140.00	7.6	44.0	5.2	0.00	45.0	5.0	0.00	0.00	90.00
143.00	N/A	44.5	N/A	0.00	46.5	N/A	0.00	0.00	90.00
144.50	N/A	73.0	N/A	0.00	75.0	N/A	0.00	0.00	90.00
147.00	N/A	68.5	N/A	0.00	72.5	N/A	0.00	0.00	90.00
164.00	N/A	71.5	N/A	0.00	74.0	N/A	0.00	0.00	90.00
170.00	7.3	70.5	5.3	0.00	71.0	5.3	0.00	0.00	90.00

FLUX RATES AND REJECTIONS FOR TEST #7 SITE G, FWKO & HTS WITH PSC - C MEMBRANES

	TUBES 1,3,5		TUBES 2,4,6	
TIME (hours)	FLUX RATE m3/m2/D	PERCENT REJECTION	FLUX RATE m3/m2/D	PERCENT REJECTION
0.25	2.7	12.8	2.5	N/A
0.57	2.6	N/A	2.3	N/A
0.75	2.6	N/A	2.3	N/A
1.00	2.3	N/A	2.0	N/A
1.50	2.3	35.8	2.1	37.35
2.00	2.2	N/A	2.0	N/A
2.50	2.1	N/A	1.9	N/A
3.00	2.1	N/A	1.9	N/A
4.00	2.1	N/A	1.8	N/A
4.50	2.0	N/A	1.8	N/A
5.00	2.0	36.2	1.8	37.85
6.00	2.0	N/A	1.8	N/A
20.50	2.2	N/A	2.0	N/A
21.00	2.1	N/A	1.9	N/A
22.00	2.1	N/A	1.9	N/A
23.00	2.0	N/A	1.7	N/A
24.00	2.1	36.7	1.8	38.27
25.00	2.2	N/A	1.9	N/A
26.00	2.2	N/A	2.0	N/A
27.00	2.1	36.5	1.9	38.73
28.00	2.0	N/A	1.8	N/A
29.00	2.5	42.0	2.0	43.13
45.00	2.1	N/A	2.0	N/A
48.00	2.1	N/A	2.0	N/A
54.00	2.3	N/A	2.2	N/A
70.00	2.1	N/A	2.1	N/A
96.00	2.3	N/A	2.2	N/A
116.00	2.0	32.2	2.1	36.94
126.00	2.1	33.5	2.1	35.63
140.00	1.8	31.6	1.8	34.38
143.00	1.8	N/A	1.9	N/A
144.50	2.9	N/A	3.0	N/A
147.00	2.8	N/A	2.9	N/A
164.00	2.9	N/A	3.0	N/A
170.00	2.8	26.6	2.9	27.03

SALT FLUX DATA FROM TEST #7 SITE G, FWKO & HTS

DATE: SEPT. 24, 1986 MEMBRANE: PSC - C

RAW DATA

TIME (MIN.)	FEED COND	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
30	48.52	9	46.07	6.8	45.65	6.2	46.07	5.4	45.96	5.6	45.54	5.3	46.6
60	48.92	6.1	46.7	5.9	46.28	4.4	46.18	4.8	46.07	4.6	45.86	4.7	46.49

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
30	1.1	5.0	0.8	5.9	0.7	5.0	0.6	5.3	0.7	6.1	0.6	4.0
60	0.7	4.5	0.7	5.4	0.5	5.6	0.6	5.8	0.6	6.3	0.6	5.0

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN. PRESSURE: 689 kPa

TEMP.: 25 °C NaCl CONC.: 35,000 ppm

APPENDIX H

FLUX DATA FOR DEVON TESTING

FLUX DATA FROM TEST #D1, SITE F, HTS

DATE: OCTOBER 22, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
0.17	362.0	425.0	3.62	221.5	425.0	2.22	5.84	12.73
0.33	210.0	N/A	2.10	148.0	N/A	1.48	9.42	19.05
0.50	152.0	N/A	1.52	122.0	N/A	1.22	12.16	23.31
0.67	128.0	N/A	1.28	110.0	N/A	1.10	14.54	26.65
0.83	115.0	N/A	1.15	102.0	N/A	1.02	16.71	29.46
1.00	111.0	375.0	1.11	102.0	375.0	1.02	18.84	32.01
1.25	98.0	N/A	1.47	93.3	N/A	1.40	21.71	35.18
1.50	92.0	N/A	1.38	89.3	N/A	1.34	24.43	37.91
1.75	85.3	N/A	1.28	84.0	N/A	1.26	26.97	40.27
2.00	84.0	650.0	1.26	84.7	650.0	1.27	29.50	42.44
2.25	78.0	N/A	1.17	78.7	N/A	1.18	31.85	44.32
2.75	74.0	640.0	2.22	76.0	640.0	2.28	36.35	47.61
19.75	41.3	175.0	0.62	46.0	175.0	0.69	37.66	48.49
20.00	42.0	N/A	0.63	46.0	N/A	0.69	38.98	49.35
20.50	41.0	N/A	1.23	44.8	N/A	1.35	41.55	50.95
21.00	40.7	250.0	1.22	44.7	250.0	1.34	44.11	52.44
21.50	40.0	250.0	1.20	43.3	250.0	1.30	46.61	53.82
22.00	38.7	275.0	1.16	42.0	275.0	1.26	49.03	55.07
22.50	38.0	275.0	1.14	41.3	275.0	1.24	51.41	56.24
23.00	38.3	270.0	1.15	41.3	270.0	1.24	53.80	57.36
23.50	37.0	280.0	1.11	40.0	280.0	1.20	56.11	58.38
24.00	37.3	275.0	1.12	40.7	275.0	1.22	58.45	59.37
24.50	34.8	275.0	1.05	37.7	275.0	1.13	60.63	60.25
25.00	35.8	280.0	1.08	38.8	280.0	1.17	62.87	61.11
25.50	37.0	275.0	1.11	40.0	275.0	1.20	65.18	61.97
26.00	34.3	275.0	1.03	37.0	275.0	1.11	67.32	62.73
26.50	34.0	280.0	1.02	36.7	280.0	1.10	69.44	63.45
44.50	27.3	150.0	0.82	29.3	150.0	0.88	71.14	64.67
45.00	27.7	150.0	0.83	29.7	150.0	0.89	72.86	66.23
45.50	27.7	150.0	0.83	30.0	150.0	0.90	74.59	67.80
46.00	28.0	150.0	0.84	30.0	150.0	0.90	76.33	69.39
46.50	28.8	150.0	1.87	30.7	150.0	0.92	79.11	71.92
47.00	29.0	150.0	0.87	31.2	150.0	0.94	80.92	73.56
47.50	28.7	150.0	0.86	30.7	150.0	0.92	82.70	75.18
48.00	28.5	150.0	0.86	30.7	150.0	0.92	84.47	76.79
48.50	28.0	150.0	0.84	29.8	150.0	0.90	86.21	78.37
49.00	27.7	150.0	0.83	29.2	150.0	0.88	87.91	79.92
49.50	27.3	150.0	0.82	29.2	150.0	0.88	89.61	81.46
50.00	28.7	150.0	0.86	30.3	150.0	0.91	91.38	83.07
50.50	27.7	150.0	0.83	29.7	150.0	0.89	93.10	84.63
51.00	28.0	150.0	0.84	29.7	150.0	0.89	94.83	86.20
51.50	27.3	150.0	0.82	28.8	150.0	0.87	96.51	87.74
52.00	28.7	150.0	0.86	29.7	150.0	0.89	98.26	89.33
52.50	27.7	155.0	0.83	29.0	155.0	0.87	99.96	90.87
75.50	28.0	200.0	N/A	29.0	200.0	0.00	99.96	90.87
98.50	30.0	275.0	N/A	28.5	275.0	0.00	99.96	90.87

FLUX DATA FROM TEST #D1, SITE F, HTS

DATE: OCTOBER 22, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5,& 6			TOTAL	
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)	PERM. VOL. (Litres)	% VOL. RED.
116.50	32.3	250.0	N/A	28.5	250.0	N/A	99.96	90.87
118.00	63.0	350.0	N/A	53.0	350.0	N/A	99.96	90.87
118.50	58.0	330.0	N/A	49.0	330.0	N/A	99.96	90.87
119.00	57.0	325.0	N/A	48.0	325.0	N/A	99.96	90.87
119.50	57.0	325.0	N/A	48.0	325.0	N/A	99.96	90.87
120.50	56.0	325.0	N/A	47.0	325.0	N/A	99.96	90.87
121.00	53.0	325.0	N/A	46.0	325.0	N/A	99.96	90.87
121.50	52.5	325.0	N/A	44.0	325.0	N/A	99.96	90.87
122.00	51.7	325.0	N/A	45.0	325.0	N/A	99.96	90.87
122.50	52.0	325.0	N/A	44.0	325.0	N/A	99.96	90.87
123.00	52.0	320.0	N/A	46.5	320.0	N/A	99.96	90.87
138.50	46.0	350.0	N/A	42.0	350.0	N/A	99.96	90.87
140.00	45.8	350.0	N/A	43.0	350.0	N/A	99.96	90.87
140.17	47.4	350.0	0.47	41.7	350.0	0.42	100.85	91.68
140.33	45.7	350.0	0.46	40.50	350.0	.41	101.71	92.47
140.50	45.2	375.0	0.45	40.10	375.0	.40	102.57	93.24
140.67	44.7	390.0	0.45	39.70	390.0	.40	103.41	94.01
140.83	45.8	390.0	0.46	40.50	390.0	.41	104.27	94.79
141.00	46.2	415.0	0.46	41.30	415.0	.41	105.15	95.59
141.17	45.8	415.0	0.46	40.50	415.0	.41	106.01	96.37
141.50	45.8	425.0	N/A	41.25	425.0	N/A	106.01	96.37
142.00	47.5	425.0	N/A	40.50	425.0	N/A	106.01	96.37
142.50	47.0	420.0	N/A	40.00	420.0	N/A	106.01	96.37
144.00	47.0	425.0	N/A	41.50	425.0	N/A	106.01	96.37
144.50	46.0	425.0	N/A	42.00	425.0	N/A	106.01	96.37
145.00	47.8	420.0	N/A	41.75	420.0	N/A	106.01	96.37
145.50	45.5	425.0	N/A	42.25	425.0	N/A	106.01	96.37
146.00	47.5	420.0	N/A	42.50	420.0	N/A	106.01	96.37

FLUX RATES FOR TEST #D1, SITE F, HTS
WITH FLT- C MEMBRANES

	TUBES 1,2&3	TUBES 4,5&6
TIME (hours)	FLUX RATE m3/m2/D	FLUX RATE m3/m2/D
0.17	14.59	8.93
0.33	8.46	5.96
0.50	6.13	4.92
0.67	5.16	4.43
0.83	4.63	4.11
1.00	4.47	4.11
1.25	3.95	3.76
1.50	3.71	3.60
1.75	3.44	3.39
2.00	3.39	3.41
2.25	3.14	3.17
2.75	2.98	3.06
19.75	1.67	1.85
20.00	1.69	1.85
20.50	1.65	1.81
21.00	1.64	1.80
21.50	1.61	1.75
22.00	1.56	1.69
22.50	1.53	1.67
23.00	1.54	1.67
23.50	1.49	1.61
24.00	1.50	1.64
24.50	1.40	1.52
25.00	1.44	1.56
25.50	1.49	1.61
26.00	1.38	1.49
26.50	1.37	1.48
44.50	1.10	1.18
45.00	1.12	1.20
45.50	1.12	1.21
46.00	1.13	1.21
46.50	1.16	1.24
47.00	1.17	1.26
47.50	1.16	1.24
48.00	1.15	1.24
48.50	1.13	1.20
49.00	1.12	1.18
49.50	1.10	1.18
50.00	1.16	1.22
50.50	1.12	1.20
51.00	1.13	1.20
51.50	1.10	1.16
52.00	1.16	1.20
52.50	1.12	1.17
75.50	1.13	1.17
98.50	1.21	1.15
116.50	1.30	1.15
118.00	2.54	2.14
118.50	2.34	1.97
119.00	2.30	1.93
119.50	2.30	1.93
120.50	2.26	1.89
121.00	2.14	1.85
121.50	2.12	1.77
122.00	2.08	1.81
122.50	2.10	1.77
123.00	2.10	1.87
138.50	1.85	1.69
140.00	1.84	1.73
140.17	1.91	1.68
140.33	1.84	1.63
140.50	1.82	1.62
140.67	1.80	1.60
140.83	1.85	1.63
141.00	1.86	1.66
141.17	1.85	1.63
141.50	1.84	1.66
142.00	1.91	1.63
142.50	1.89	1.61
144.00	1.89	1.67
144.50	1.85	1.69
145.00	1.92	1.68
145.50	1.83	1.70
146.00	1.91	1.71

SALT FLUX DATA FROM TEST #D1, SITE F, HTS

DATE: OCTOBER 22, 1986 MEMBRANE: FLT - C

RAW DATA

TIME (MIN.)	FEED COND	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
60	44.16	25	43.41	26	44.37	20	43.2	18	43.94	18	44.26	8	45.52

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
60	3.0	1.7	3.1	0.0	2.4	2.2	2.2	0.5	2.2	0.0	1.0	0.0

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN. PRESSURE: 689 kPa

TEMP.: 25 °C NaCl CONC.: 35,000 ppm

FLUX DATA FROM TEST #D2, SITE E, Wellhead

DATE: OCTOBER 30, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
0.17	111.0	575.0	1.11	88.5	550.0	0.89	2.00	4.75
0.33	95.0	500.0	0.95	80.0	500.0	0.80	3.75	8.56
0.50	84.5	500.0	0.85	73.0	500.0	0.73	5.32	11.74
0.67	80.0	550.0	0.80	70.0	550.0	0.70	6.82	14.57
0.83	77.0	550.0	0.77	69.0	550.0	0.69	8.28	17.15
1.00	73.0	575.0	0.73	65.0	575.0	0.65	9.66	19.45
1.25	72.3	625.0	1.09	65.3	625.0	0.98	11.73	22.67
1.50	68.0	650.0	1.02	63.3	650.0	0.95	13.70	25.51
1.75	66.7	650.0	1.00	61.3	650.0	0.92	15.62	28.08
2.00	63.3	700.0	0.95	58.7	700.0	0.88	17.45	30.37
2.25	62.0	750.0	0.93	57.7	750.0	0.87	19.24	32.48
2.50	60.0	800.0	0.90	56.0	800.0	0.84	20.98	34.40
2.75	59.3	850.0	0.89	54.7	850.0	0.82	22.69	36.19
3.00	58.0	850.0	0.87	55.0	850.0	0.83	24.39	37.87
3.25	56.0	850.0	0.84	53.3	850.0	0.80	26.03	39.42
3.50	54.7	850.0	0.82	52.7	850.0	0.79	27.64	40.86
4.00	51.3	850.0	1.54	49.8	850.0	1.50	30.67	43.40
4.50	49.3	850.0	1.48	48.7	850.0	1.46	33.61	45.66
5.00	47.3	850.0	1.42	46.7	850.0	1.40	36.43	47.66
5.50	46.3	850.0	1.39	45.0	850.0	1.35	39.17	49.48
6.00	46.0	850.0	1.38	45.0	850.0	1.35	41.90	51.16
6.50	45.0	850.0	1.35	44.7	850.0	1.34	44.59	52.71
7.00	44.0	850.0	1.32	44.0	850.0	1.32	47.23	54.14
7.50	42.0	850.0	1.26	42.0	850.0	1.26	49.75	55.43
8.00	41.5	850.0	1.25	42.0	850.0	1.26	52.26	56.64
24.00	32.3	215.0	0.97	31.7	215.0	0.95	54.18	57.53
24.50	32.0	250.0	0.96	34.8	250.0	1.05	56.18	58.41
25.00	31.8	300.0	0.96	34.5	300.0	1.04	58.17	59.25
25.50	31.2	325.0	0.94	34.0	325.0	1.02	60.13	60.05
26.00	31.8	375.0	0.96	34.7	375.0	1.04	62.12	62.04
26.50	30.3	400.0	0.91	33.3	400.0	1.00	64.03	63.95
27.00	30.7	400.0	0.92	33.7	400.0	1.01	65.96	65.87
27.50	30.8	400.0	0.93	34.3	400.0	1.03	67.92	67.83
28.00	29.8	400.0	0.90	33.2	400.0	1.00	69.81	69.71
28.50	29.7	400.0	0.89	33.0	400.0	0.99	71.69	71.59
29.50	29.4	400.0	1.77	32.8	400.0	1.97	75.42	75.32
30.00	29.7	400.0	0.89	33.0	400.0	0.99	77.30	77.20
30.50	29.7	400.0	0.89	32.3	400.0	0.97	79.16	79.06
31.00	29.7	400.0	0.89	32.5	400.0	0.98	81.03	80.92
31.50	29.5	400.0	0.89	32.7	400.0	0.98	82.89	82.78
32.00	29.3	400.0	0.88	32.3	400.0	0.97	84.74	84.63
48.00	30.0	175.0	N/A	33.0	175.0	N/A	N/A	84.63
72.00	31.0	200.0	N/A	34.0	200.0	N/A	N/A	84.63
95.50	33.5	200.0	N/A	36.0	200.0	N/A	N/A	84.63
96.00	30.0	200.0	N/A	36.0	200.0	N/A	N/A	84.63
96.50	33.0	200.0	N/A	35.5	200.0	N/A	N/A	84.63

FLUX DATA FROM TEST #D2, SITE E, Wellhead

DATE: OCTOBER 30, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5,& 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
98.50	69.0	1200.0	N/A	55.0	600.0	N/A	N/A	84.63
99.00	48.0	1000.0	N/A	42.0	600.0	N/A	N/A	84.63
100.00	41.0	600.0	N/A	39.0	600.0	N/A	N/A	84.63
101.00	39.5	600.0	N/A	38.5	500.0	N/A	N/A	84.63
102.00	38.0	550.0	N/A	36.0	450.0	N/A	N/A	84.63
103.00	36.0	500.0	N/A	34.0	425.0	N/A	N/A	84.63
104.00	36.0	550.0	N/A	34.5	425.0	N/A	N/A	84.63
105.00	35.0	550.0	N/A	33.5	450.0	N/A	N/A	84.63
120.00	30.0	425.0	N/A	30.0	425.0	N/A	N/A	84.63

FLUX RATES FOR TEST #D2, SITE E, Wellhead
WITH FLT - C MEMBRANES

DATE: OCTOBER 30, 1986

MEMBRANE : FLT - C

	TUBES 1,2&3	TUBES 4,5&6
TIME (hours)	FLUX RATE m3/m2/D	FLUX RATE m3/m2/D
0.17	4.47	3.57
0.33	3.83	3.22
0.50	3.41	2.94
0.67	3.22	2.82
0.83	3.10	2.78
1.00	2.94	2.62
1.25	2.91	2.63
1.50	2.74	2.55
1.75	2.69	2.47
2.00	2.55	2.36
2.25	2.50	2.32
2.50	2.42	2.26
2.75	2.39	2.20
3.00	2.34	2.22
3.25	2.26	2.15
3.50	2.20	2.12
4.00	2.07	2.01
4.50	1.99	1.96
5.00	1.91	1.88
5.50	1.87	1.81
6.00	1.85	1.81
6.50	1.81	1.80
7.00	1.77	1.77
7.50	1.69	1.69
8.00	1.67	1.69
24.00	1.30	1.28
24.50	1.29	1.40
25.00	1.28	1.39

	TUBES 1,2&3	TUBES 4,5&6
TIME (hours)	FLUX RATE m3/m2/D	FLUX RATE m3/m2/D
25.50	1.26	1.37
26.00	1.28	1.40
26.50	1.22	1.34
27.00	1.24	1.36
27.50	1.24	1.38
28.00	1.20	1.34
28.50	1.20	1.33
29.50	1.19	1.32
30.00	1.20	1.33
30.50	1.20	1.30
31.00	1.20	1.31
31.50	1.19	1.32
32.00	1.18	1.30
48.00	1.21	1.33
72.00	1.25	1.37
95.50	1.35	1.45
96.00	1.21	1.45
96.50	1.33	1.43
98.50	2.78	2.22
99.00	1.93	1.69
100.00	1.65	1.57
101.00	1.59	1.55
102.00	1.53	1.45
103.00	1.45	1.37
104.00	1.45	1.39
105.00	1.41	1.35
120.00	1.21	1.21

FLUX DATA FROM TEST #D3, SITE E, IGF

DATE: NOVEMBER 5, 1986 MEMBRANE : FLT - C

	TUBES 1,2 & 3			TUBES 4,5 & 6				
TIME (hrs.)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)	TOTAL PERM. VOL. (Litres)	% VOL. RED.
0.17	90.5	350	0.91	81.0	225	0.81	1.72	4.11
0.33	77.0	300	0.77	75.0	215	0.75	3.24	7.48
0.50	73.0	300	0.73	72.0	225	0.72	4.69	10.48
0.67	70.0	300	0.70	71.0	225	0.71	6.10	13.22
0.83	68.0	275	0.68	69.5	225	0.70	7.47	15.74
1.00	64.0	275	0.64	66.0	225	0.66	8.77	17.98
1.25	60.7	275	0.91	63.3	225	0.95	10.63	21.00
1.50	59.7	300	0.90	62.0	275	0.93	12.46	23.74
1.75	56.0	315	0.84	59.3	300	0.89	14.19	26.18
2.00	54.7	325	0.82	58.0	325	0.87	15.88	28.41
2.50	52.5	350	1.58	56.5	340	1.70	19.15	32.37
3.00	49.2	500	1.48	53.3	400	1.60	22.22	35.71
3.50	46.7	500	1.40	51.0	450	1.53	25.15	38.60
4.00	43.7	500	1.31	48.3	500	1.45	27.91	41.10
5.00	42.2	500	2.53	46.8	500	2.81	33.25	45.39
6.00	39.3	500	2.36	44.2	500	2.65	38.26	48.89
7.00	37.3	475	2.24	42.0	475	2.52	43.02	51.82
8.00	35.3	425	2.12	39.8	425	2.39	47.53	54.30
8.50	34.2	400	1.03	39.0	400	1.17	49.72	55.42
24.50	32.7	200	0.98	36.5	200	1.10	51.80	56.42
25.00	31.2	200	0.94	34.7	200	1.04	53.77	57.34
25.50	31.0	200	0.93	34.5	200	1.04	55.74	58.22
26.00	31.0	200	0.93	34.3	200	1.03	57.70	59.06
27.00	32.3	200	1.94	36.1	200	2.17	61.80	60.71
28.00	30.8	200	1.85	34.7	200	2.08	65.73	62.17
29.00	30.2	225	1.81	33.7	225	2.02	69.56	63.49
30.00	29.2	275	1.75	32.5	275	1.95	73.26	64.68
31.00	29.1	250	1.75	32.4	250	1.95	76.95	65.80
32.00	28.9	350	1.74	32.3	350	1.94	80.62	66.81
48.00	28.8	225	0.87	31.3	225	0.94	82.43	68.31
48.50	27.7	225	0.83	30.7	225	0.92	84.18	69.76
49.00	27.7	225	0.83	30.7	225	0.92	85.93	71.21
49.50	27.3	200	0.82	30.3	200	0.91	87.66	72.64
50.00	28.3	200	0.85	31.0	200	0.93	89.44	74.12
50.50	28.0	225	0.84	31.0	225	0.93	91.21	75.59
52.25	46.7	500	0.70	50.0	500	0.75	92.66	76.79
52.50	45.3	450	0.68	48.7	450	0.73	94.07	77.96
53.00	44.2	400	1.33	47.0	400	1.41	96.80	80.22
54.00	42.3	425	2.54	45.0	425	2.70	102.04	84.56
55.00	42.5	425	2.55	44.5	425	2.67	107.26	88.89
55.50	41.3	700	1.24	43.7	750	1.31	109.81	91.00
77.00	37.0	750	N/A	32.5	730	N/A	N/A	91.00
95.00	38.0	450	N/A	32.0	500	N/A	N/A	91.00
119.00	36.0	650	N/A	32.0	600	N/A	N/A	91.00
120.00	34.5	650	N/A	32.0	600	N/A	N/A	91.00
122.00	44.0	1600	N/A	44.0	1400	N/A	N/A	91.00

FLUX DATA FROM TEST #D3, SITE E, IGF

DATE: NOVEMBER 5,

MEMBRANE :FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5,& 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
123.00	38.0	960	N/A	38.0	900	N/A	N/A	91.00
123.50	36.0	900	N/A	36.0	900	N/A	N/A	91.00
126.00	34.5	880	N/A	35.0	880	N/A	N/A	91.00
127.00	34.0	700	N/A	33.5	680	N/A	N/A	91.00
143.00	29.0	700	N/A	30.0	650	N/A	N/A	91.00
144.00	29.0	670	N/A	30.5	700	N/A	N/A	91.00
167.00	28.5	620	N/A	26.0	650	N/A	N/A	91.00
169.00	27.0	700	N/A	27.0	700	N/A	N/A	91.00
171.00	28.0	680	N/A	30.0	700	N/A	N/A	91.00
173.00	28.5	700	N/A	28.0	720	N/A	N/A	91.00
175.00	28.0	750	N/A	26.0	750	N/A	N/A	91.00
191.00	27.0	750	N/A	27.0	720	N/A	N/A	91.00
192.00	28.0	780	N/A	28.0	740	N/A	N/A	91.00
193.00	28.0	730	N/A	29.0	750	N/A	N/A	91.00
194.00	28.0	740	N/A	28.0	750	N/A	N/A	91.00
195.00	28.0	740	N/A	28.0	730	N/A	N/A	91.00
197.00	28.0	740	N/A	26.0	740	N/A	N/A	91.00
199.00	27.0	720	N/A	28.0	740	N/A	N/A	91.00
215.00	26.0	750	N/A	27.0	770	N/A	N/A	91.00
217.00	26.0	770	N/A	25.0	760	N/A	N/A	91.00
219.00	48.0	3250	N/A	48.0	3200	N/A	N/A	91.00
220.00	33.0	2900	N/A	35.0	3000	N/A	N/A	91.00
221.00	29.0	2250	N/A	30.0	2250	N/A	N/A	91.00
222.00	28.0	2050	N/A	26.0	2000	N/A	N/A	91.00

FLUX RATES FOR TEST #D3, SITE E, IGF WITH FLT - C MEMBRANES

TIME (hours)	TUBES 1,2&3 FLUX RATE m3/m2/D	TUBES 4,5&6 FLUX RATE m3/m2/D
0.17	3.65	3.26
0.33	3.10	3.02
0.50	2.94	2.90
0.67	2.82	2.86
0.83	2.74	2.80
1.00	2.58	2.66
1.25	2.45	2.55
1.50	2.40	2.50
1.75	2.26	2.39
2.00	2.20	2.34
2.50	2.12	2.28
3.00	1.98	2.15
3.50	1.88	2.06
4.00	1.76	1.95
5.00	1.70	1.88
6.00	1.58	1.78
7.00	1.50	1.69
8.00	1.42	1.61
8.50	1.38	1.57
24.50	1.32	1.47
25.00	1.26	1.40
25.50	1.25	1.39
26.00	1.25	1.38
27.00	1.30	1.45
28.00	1.24	1.40
29.00	1.22	1.36
30.00	1.18	1.31
31.00	1.17	1.31
32.00	1.17	1.30
48.00	1.16	1.26
48.50	1.12	1.24
49.00	1.12	1.24
49.50	1.10	1.22
50.00	1.14	1.25
50.50	1.13	1.25
52.25	1.88	2.02
52.50	1.83	1.96
53.00	1.78	1.89
54.00	1.71	1.81
55.00	1.71	1.79
55.50	1.67	1.76
77.00	1.49	1.31
95.00	1.53	1.29
119.00	1.45	1.29
120.00	1.39	1.29
122.00	1.77	1.77
123.00	1.53	1.53
123.50	1.45	1.45
126.00	1.39	1.41
127.00	1.37	1.35
143.00	1.17	1.21
144.00	1.17	1.23
167.00	1.15	1.05
169.00	1.09	1.09
171.00	1.13	1.21
173.00	1.15	1.13
175.00	1.13	1.05
191.00	1.09	1.09
192.00	1.13	1.13
193.00	1.13	1.17
194.00	1.13	1.13
195.00	1.13	1.13
197.00	1.13	1.05
199.00	1.09	1.13
215.00	1.05	1.09
217.00	1.05	1.01
219.00	1.93	1.93
220.00	1.33	1.41
221.00	1.17	1.21
222.00	1.13	1.05

SALT FLUX DATA FROM TEST #D3, SITE E, IGF

DATE: NOVEMBER 5, 1986

MEMBRANE: FLT - C

RAW DATA

		TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
TIME (MIN.)	FEED COND	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
60	4.9	19	4.2	26	4.6	20	4.4	17.5	4.2	14	4	8	3.7

CALCULATED FLUX RATES AND REJECTIONS

	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
TIME (MIN.)	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
60	2.3	14.3	3.1	0.0	2.4	10.2	2.1	14.3	1.7	18.4	1.0	24.5

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 689 kPa

TEMP.: 25 °C

NaCl CONC.:3,500 ppm

FLUX DATA FROM TEST #D4, SITE H, FWKO

DATE: NOVEMBER 20, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
0.22	269.0	25	3.50	138.0	25	1.80	5.30	11.70
0.42	239.0	25	2.87	123.0	35	1.48	9.65	19.44
0.67	221.0	30	3.32	113.0	40	1.70	14.67	26.83
1.00	222.0	40	4.44	117.5	50	2.35	21.46	34.92
1.25	217.0	70	3.26	113.0	60	1.69	26.41	39.77
1.50	207.0	100	3.10	107.0	100	1.61	31.12	43.76
1.75	207.0	120	3.10	108.0	100	1.62	35.84	47.26
2.00	199.0	120	2.98	105.0	120	1.57	40.39	50.24
2.25	200.0	125	3.00	106.0	130	1.59	44.98	52.93
2.50	197.0	135	2.95	104.0	130	1.56	49.49	55.30
2.75	186.0	135	2.79	97.0	150	1.46	53.74	57.33
3.00	184.0	135	2.76	97.0	145	1.45	57.95	59.16
3.25	187.0	135	2.80	97.0	140	1.46	62.21	60.86
3.50	185.0	140	2.78	97.0	150	1.46	66.45	62.42
3.75	185.0	150	2.77	97.0	150	1.46	70.68	63.86
4.00	185.0	150	2.77	97.0	150	1.46	74.91	65.19
4.25	184.0	145	2.76	97.0	165	1.46	79.13	66.42
4.50	180.0	170	2.70	97.0	190	1.45	83.28	67.55
4.65	181.0	170	1.81	98.0	190	0.98	86.07	74.15
5.00	181.0	175	3.62	97.0	200	1.94	91.63	78.94
5.25	189.0	160	2.84	101.0	150	1.52	95.99	82.70
5.50	185.0	125	2.78	100.0	120	1.50	100.27	86.39
5.75	187.0	120	2.80	100.0	100	1.50	104.57	90.09
7.00	183.0	125	N/A	100.0	120	N/A	104.57	90.09
21.00	140.0	80	N/A	90.0	90	N/A	104.57	90.09
22.00	142.0	80	N/A	89.0	90	N/A	104.57	90.09
23.00	145.0	60	N/A	94.0	90	N/A	104.57	90.09
25.00	149.0	60	N/A	94.0	80	N/A	104.57	90.09
27.00	147.0	70	N/A	92.0	75	N/A	104.57	90.09
28.00	148.0	60	N/A	94.0	75	N/A	104.57	90.09
44.00	143.0	75	N/A	85.0	75	N/A	104.57	90.09
68.00	145.0	75	N/A	100.0	70	N/A	104.57	90.09

FLUX RATES FOR TEST #D4, SITE H, FWKO WITH FLT - C MEMBRANES

	TUBES 1,2&3	TUBES 4,5&6
TIME (hours)	FLUX RATE m3/m2/D	FLUX RATE m3/m2/D
0.22	10.84	5.56
0.42	9.63	4.96
0.67	8.91	4.55
1.00	8.95	4.74
1.25	8.75	4.55
1.50	8.34	4.31
1.75	8.34	4.35
2.00	8.02	4.23
2.25	8.06	4.27
2.50	7.94	4.19
2.75	7.50	3.91
3.00	7.42	3.91
3.25	7.54	3.91
3.50	7.46	3.91
3.75	7.46	3.91
4.00	7.46	3.91
4.25	7.42	3.91
4.50	7.25	3.91
4.65	7.29	3.95
5.00	7.29	3.91
5.25	7.62	4.07
5.50	7.46	4.03
5.75	7.54	4.03
7.00	7.37	4.03
21.00	5.64	3.63
22.00	5.72	3.59
23.00	5.84	3.79
25.00	6.00	3.79
27.00	5.92	3.71
28.00	5.96	3.79
44.00	5.76	3.43
68.00	5.84	4.03

SALT FLUX DATA FROM TEST #D4, SITE H, FWKO

DATE: NOVEMBER 20, 1986

MEMBRANE: FLT - C

RAW DATA

		TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
IME MIN.)	FEED CGND	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
60	5.2	25	4.4	20	4.1	28.3	4.7	19	4.2	18.3	4.4	9.6	4.3

CALCULATED FLUX RATES AND REJECTIONS

	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
TIME (MIN.)	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
60	3.0	15.4	2.4	21.2	3.4	9.6	2.3	19.2	2.2	15.4	1.2	17.3

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 689 kPa

TEMP.: 25 °C

NaCl CONC.: 3,500 ppm

FLUX DATA FROM TEST #D5, SITE D, FWKO

DATE: NOVEMBER 25, 1986 MEMBRANE : FLT - C

TIME (hrs.)	TUBES 1,2 & 3			TUBES 4,5 & 6			TOTAL PERM. VOL. (Litres)	% VOL. RED.
	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	PERM. COLOUR (APHA)	VOL. PERM. (Litres)		
0.25	165.3	300	2.48	212.7	300	3.19	5.67	15.90
0.50	160.0	400	2.40	202.0	400	3.03	11.10	27.01
1.00	139.0	450	4.17	183.0	350	5.49	20.76	40.90
1.50	115.0	450	3.45	157.7	450	4.73	28.94	49.10
2.00	97.7	600	2.93	136.0	450	4.08	35.95	54.51
2.50	85.3	650	2.56	121.7	550	3.65	42.16	58.43
3.00	79.0	600	2.37	114.3	600	3.43	47.96	61.52
3.50	76.7	620	2.30	108.7	600	3.26	53.52	64.08
4.00	75.0	650	2.25	106.3	600	3.19	58.96	66.28
4.50	76.0	660	2.28	105.7	650	3.17	64.41	68.22
5.00	76.0	650	2.28	106.0	720	3.18	69.87	74.01
5.50	76.7	700	2.30	105.7	700	3.17	75.34	79.80
6.00	75.7	700	2.27	104.0	700	3.12	80.73	85.51
6.50	75.3	700	2.26	104.7	700	3.14	86.17	91.27
22.00	58.7	500	N/A	86.0	600	N/A	86.17	91.27
23.00	60.0	600	N/A	87.3	660	N/A	86.17	91.27
24.00	60.0	600	N/A	85.7	650	N/A	86.17	91.27
26.00	59.3	700	N/A	86.3	750	N/A	86.17	91.27
28.00	58.7	750	N/A	86.3	700	N/A	86.17	91.27
30.00	59.0	650	N/A	86.3	680	N/A	86.17	91.27
46.00	58.3	600	N/A	87.0	650	N/A	86.17	91.27
57.50	58.0	600	N/A	86.0	600	N/A	86.17	91.27

FLUX RATES FOR TEST #D5, SITE D, FWKO WITH FLT - C MEMBRANES

	TUBES 1,2&3	TUBES 4,5&6
TIME (hours)	FLUX RATE m3/m2/D	FLUX RATE m3/m2/D
0.25	6.66	8.57
0.50	6.45	8.14
1.00	5.60	7.37
1.50	4.63	6.36
2.00	3.94	5.48
2.50	3.44	4.90
3.00	3.18	4.61
3.50	3.09	4.38
4.00	3.02	4.28
4.50	3.06	4.26
5.00	3.06	4.27
5.50	3.09	4.26
6.00	3.05	4.19
6.50	3.03	4.22
22.00	2.37	3.47
23.00	2.42	3.52
24.00	2.42	3.45
26.00	2.39	3.48
28.00	2.37	3.48
30.00	2.38	3.48
46.00	2.35	3.51
57.50	2.34	3.47

SALT FLUX DATA FROM TEST #D5, SITE D, FWKO

DATE: NOVEMBER 25, 1986

MEMBRANE: FLT - C

RAW DATA

TIME (MIN.)	FEED COND	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
60	5.3	24.5	4.5	19	4.6	29.7	4.7	26	4.9	25.5	4.7	30	5.2

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	TUBE #1		TUBE #2		TUBE #3		TUBE #4		TUBE #5		TUBE #6	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
60	2.9	15.1	2.3	13.2	3.6	11.3	3.1	7.5	3.1	11.3	3.6	1.9

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 689 kPa

TEMP.: 25 °C

NaCl CONC.: 3,500 ppm

APPENDIX I

FLUX DATA FOR S2 TESTING

OPERATING CONDITIONS FOR TEST S2 - 1, SITE D, Skim Tank

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 17	65	345	20	Recycle at 0 % VR
17 - 21.5	65	517	20	Recycle at 0 % VR
21.5 - 26	65	689	20	Recycle at 0 % VR
26 - 40	75	689	20	Recycle at 0 % VR
40 - 41.5	65	689	20	Recycle at 0 % VR
41.5 - 45		Clean With MC - 40		
45 - 50	65	689	20	Concentrate to 40 % VR
50 - 63	65	689	20	Recycle at 40 % VR
63 - 65		Clean With MC - 40		
65 - 139	65	689	20	Recycle at 40 % VR
139 - 140.5	65	689	20	Recycle at 40 % VR
140.5 - 141.5	65	689	20	Recycle at 40 % VR
141.5 - 142	65	689	20	Recycle at 40 % VR

FLUX DATA FROM TEST S2 - 1, SITE D, Skim Tank

DATE: FEBRUARY 3, 1987 MEMBRANES: FLT - C / FLT - B / FLT-Q

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C)			TUBES 2 & 5 (FLT - B)			TUBES 3 & 4 (FLT-Q)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
0.0	1500	36.0	175	N/A	38.0	180	N/A	40.5	185	N/A	N/A	N/A
1.0	N/A	33.0	N/A	N/A	34.0	N/A	N/A	36.0	N/A	N/A	N/A	N/A
2.0	2000	29.0	205	N/A	30.3	175	N/A	34.0	225	N/A	N/A	N/A
16.0	N/A	23.0	N/A	N/A	19.0	N/A	N/A	23.0	N/A	N/A	N/A	N/A
17.0	2000	22.3	175	N/A	23.3	185	N/A	24.0	200	N/A	N/A	N/A
17.5	2000	34.5	175	N/A	32.5	175	N/A	37.5	230	N/A	N/A	N/A
18.5	N/A	33.0	N/A	N/A	34.0	N/A	N/A	35.8	N/A	N/A	N/A	N/A
19.50	N/A	32.0	N/A	N/A	33.0	N/A	N/A	35.0	N/A	N/A	N/A	N/A
20.50	N/A	31.0	N/A	N/A	33.8	N/A	N/A	35.3	N/A	N/A	N/A	N/A
21.50	2000	31.5	175	N/A	32.5	175	N/A	32.4	175	N/A	N/A	N/A
22.00	2000	43.0	175	N/A	42.0	175	N/A	45.2	175	N/A	N/A	N/A
23.00	N/A	41.5	N/A	N/A	40.5	N/A	N/A	43.3	N/A	N/A	N/A	N/A
24.00	2000	40.5	175	N/A	37.5	180	N/A	41.0	175	N/A	N/A	N/A
25.00	N/A	38.7	N/A	N/A	35.3	N/A	N/A	42.0	N/A	N/A	N/A	N/A
26.00	2500	38.5	175	N/A	38.0	175	N/A	40.0	175	N/A	N/A	N/A
26.50	2500	44.0	175	N/A	43.0	175	N/A	45.0	175	N/A	N/A	N/A
27.50	N/A	41.8	N/A	N/A	40.8	N/A	N/A	43.8	N/A	N/A	N/A	N/A
29.50	N/A	39.0	N/A	N/A	38.6	N/A	N/A	40.0	N/A	N/A	N/A	N/A
39.00	N/A	31.0	N/A	N/A	30.3	N/A	N/A	30.3	N/A	N/A	N/A	N/A
40.00	2500	30.5	175	N/A	29.5	175	N/A	29.3	175	N/A	N/A	N/A
40.50	N/A	25.0	N/A	N/A	25.0	N/A	N/A	26.3	N/A	N/A	N/A	N/A
41.50	2500	26.0	175	N/A	25.0	175	N/A	26.0	175	N/A	N/A	N/A
44.00	2500	41.0	175	N/A	34.8	175	N/A	39.8	175	N/A	N/A	N/A
45.00	2500	38.5	175	N/A	34.0	175	N/A	36.3	175	N/A	N/A	N/A
45.50	2750	37.3	275	0.56	31.7	275	0.48	36.5	275	0.55	1.58	3.8
45.75	N/A	35.0	N/A	0.53	30.3	N/A	0.46	34.7	N/A	0.52	3.08	7.2
46.00	N/A	33.3	N/A	0.50	29.0	N/A	0.44	33.0	N/A	0.50	4.51	10.1
46.25	N/A	32.0	N/A	0.48	28.0	N/A	0.42	32.0	N/A	0.48	5.89	12.8
46.75	N/A	30.7	N/A	0.92	27.0	N/A	0.81	30.3	N/A	0.91	8.53	18.6
47.25	2750	29.3	275	0.88	26.0	275	0.78	29.3	275	0.88	11.07	24.1

FLUX DATA FROM TEST S2 - 1, SITE D, Skim Tank

DATE: FEBRUARY 3, 1987 MEMBRANES: FLT - C / FLT - B / FLT-Q

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C)			TUBES 2 & 5 (FLT - B)			TUBES 3 & 4 (FLT-Q)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
47.8	N/A	28.2	N/A	0.85	25.0	N/A	0.75	28.0	N/A	0.84	13.51	29.4
48.3	N/A	27.2	N/A	0.82	24.3	N/A	0.73	27.0	N/A	0.81	15.86	34.6
48.8	N/A	26.3	N/A	0.79	23.7	N/A	0.71	26.3	N/A	0.79	18.15	39.6
49.3	N/A	26.0	N/A	N/A	23.5	N/A	N/A	25.1	N/A	N/A	N/A	N/A
64.0	2750	19.0	275	N/A	17.5	275	N/A	18.5	275	N/A	N/A	N/A
65.0	N/A	18.7	N/A	N/A	17.3	N/A	N/A	18.5	N/A	N/A	N/A	N/A
68.0	2750	105.0	275	N/A	112.0	275	N/A	107.0	275	N/A	N/A	N/A
70.0	N/A	90.0	N/A	N/A	92.5	N/A	N/A	96.0	N/A	N/A	N/A	N/A
72.0	N/A	86.5	N/A	N/A	96.0	N/A	N/A	94.0	N/A	N/A	N/A	N/A
94.0	2750	78.0	275	N/A	82.0	275	N/A	84.5	275	N/A	N/A	N/A
118.0	N/A	75.5	N/A	N/A	77.5	N/A	N/A	82.0	N/A	N/A	N/A	N/A
136.0	2750	77.5	275	N/A	80.0	275	N/A	84.5	275	N/A	N/A	N/A
139.0	N/A	78.5	N/A	N/A	79.5	N/A	N/A	87.5	N/A	N/A	N/A	N/A
139.5	N/A	74.5	N/A	N/A	77.5	N/A	N/A	82.0	N/A	N/A	N/A	N/A
140.5	N/A	74.7	N/A	N/A	78.0	N/A	N/A	82.0	N/A	N/A	N/A	N/A
141.0	N/A	76.0	N/A	N/A	78.7	N/A	N/A	84.5	N/A	N/A	N/A	N/A
141.5	N/A	75.0	N/A	N/A	79.5	N/A	N/A	82.3	N/A	N/A	N/A	N/A
142.0	N/A	76.5	N/A	N/A	78.0	N/A	N/A	83.0	N/A	N/A	N/A	N/A

FLUX RATES FOR TEST #S2 - 1, SITE D, Skim Tank
WITH FLT - C / FLT - B / FLT - Q MEMBRANES

TIME (hours)	FLT - C FLUX RATE m3/m2/D	FLT - B FLUX RATE m3/m2/D	FLT - Q FLUX RATE m3/m2/D
0.0	2.16	2.28	2.43
1.0	1.98	2.04	2.16
2.0	1.74	1.82	2.04
16.0	1.38	1.14	1.38
17.0	1.34	1.40	1.44
17.5	2.07	1.95	2.25
18.5	1.98	2.04	2.15
19.50	1.92	1.98	2.10
20.50	1.86	2.03	2.12
21.50	1.89	1.95	1.94
22.00	2.58	2.52	2.71
23.00	2.49	2.43	2.60
24.00	2.43	2.25	2.46
25.00	2.32	2.12	2.52
26.00	2.31	2.28	2.40
26.50	2.64	2.58	2.70
27.50	2.51	2.45	2.63
29.50	2.34	2.32	2.40
39.00	1.86	1.82	1.82
40.00	1.83	1.77	1.76
40.50	1.50	1.50	1.58
41.50	1.56	1.50	1.56
44.00	2.46	2.09	2.39
45.00	2.31	2.04	2.18
45.50	2.24	1.90	2.19
45.75	2.10	1.82	2.08
46.00	2.00	1.74	1.98
46.25	1.92	1.68	1.92
46.75	1.84	1.62	1.82
47.25	1.76	1.56	1.76
47.8	1.69	1.50	1.68
48.3	1.63	1.46	1.62
48.8	1.58	1.42	1.58
49.3	1.56	1.41	1.51
64.0	1.14	1.05	1.11
65.0	1.12	1.04	1.11
68.0	6.30	6.72	6.42
70.0	5.40	5.55	5.76
72.0	5.19	5.76	5.64
94.0	4.68	4.92	5.07
118.0	4.53	4.65	4.92
136.0	4.65	4.80	5.07
139.0	4.71	4.77	5.25
139.5	4.47	4.65	4.92
140.5	4.48	4.68	4.92
141.0	4.56	4.72	5.07
141.5	4.50	4.77	4.94
142.0	4.59	4.68	4.98

SALT FLUX DATA FROM TEST #S2-1, SITE D, Skim Tank

DATE: FEBRUARY 3, 1987 MEMBRANE: FLT - C / FLT - B / FLT-Q

RAW DATA

TIME (MIN.)	FEED COND	FLT - C		FLT - B		FLT - Q		FLT - Q		FLT - B		FLT - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	2.01	12	0.99	11.5	1.023	13	0.928	11	1.127	9.5	1.08	8.75	1.145
180	2.05	12	1.002	12	0.947	14	0.946	11.47	1.103	11	1.003	10	1.211

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	FLT - C		FLT - B		FLT - Q		FLT - Q		FLT - B		FLT - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	0.7	50.7	0.7	49.1	0.8	53.8	0.7	43.9	0.6	46.3	0.5	43.0
180	0.7	51.1	0.7	53.8	0.8	53.9	0.7	46.2	0.7	51.1	0.6	40.9

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN. PRESSURE: 517 kPa

TEMP: 33 °C NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S2 - 2, SITE D, Skim Tank

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 1.5	65	689	20	Recycle at 0 % VR
1.5 - 9.5	65	689	20	Recycle at 0 % VR

FLUX DATA FROM TEST S2 - 2, SITE D, Skim Tank

DATE: FEBRUARY 11, 1987 MEMBRANES: FLT - C(2) / FLT - B(2) / FLT-Q(2)

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C(2))			TUBES 2 & 5 (FLT - B(2))			TUBES 3 & 4 (FLT-Q(2))			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
0.0	N/A	65.0	N/A	N/A	65.5	N/A	N/A	72.5	N/A	N/A	N/A	N/A
0.5	2150	49.0	350	N/A	49.0	325	N/A	53.0	325	N/A	N/A	N/A
1.0	2000	40.3	300	N/A	40.0	300	N/A	41.7	325	N/A	N/A	N/A
1.5	2000	34.0	275	N/A	36.0	275	N/A	35.0	275	N/A	N/A	N/A
4.3	2050	64.0	200	N/A	67.0	200	N/A	71.5	200	N/A	N/A	N/A
4.5	N/A	54.5	N/A	N/A	56.5	N/A	N/A	61.5	N/A	N/A	N/A	N/A
5.0	2750	45.0	175	N/A	47.0	180	N/A	52.5	175	N/A	N/A	N/A
5.5	N/A	42.5	N/A	N/A	44.0	N/A	N/A	50.5	N/A	N/A	N/A	N/A
6.0	1900	38.5	175	N/A	44.0	180	N/A	47.5	175	N/A	N/A	N/A
7.5	N/A	38.0	N/A	N/A	38.5	N/A	N/A	43.5	N/A	N/A	N/A	N/A
8.5	N/A	33.3	N/A	N/A	35.6	N/A	N/A	39.5	N/A	N/A	N/A	N/A
9.5	N/A	31.2	N/A	N/A	33.2	N/A	N/A	34.2	N/A	N/A	N/A	N/A

FLUX RATES FOR TEST #S2 - 2, SITE D, Skim Tank
WITH FLT - C(2) / FLT - B(2) / FLT - Q(2) MEMBRANES

TIME (hrs.)	FLT - C(2) FLUX RATE m3/m2/D	FLT - B(2) FLUX RATE m3/m2/D	FLT - Q(2) FLUX RATE m3/m2/D
0.0	3.90	3.93	4.35
0.5	2.94	2.94	3.18
1.0	2.42	2.40	2.50
1.5	2.04	2.16	2.10
4.3	3.84	4.02	4.29
4.5	3.27	3.39	3.69
5.0	2.70	2.82	3.15
5.5	2.55	2.64	3.03
6.0	2.31	2.64	2.85
7.5	2.28	2.31	2.61
8.5	2.00	2.14	2.37
9.5	1.87	1.99	2.05

(2) denotes second test performed with actual membrane

SALT FLUX DATA FROM TEST #S2-2, SITE D, Skim Tank

DATE: FEBRUARY 10, 1987

MEMBRANE: FLT - C(2) / FLT - B(2) / FLT-Q(2)

RAW DATA

		FLT - C(2)		FLT - B(2)		FLT - Q(2)		FLT - Q(2)		FLT - B(2)		FLT - C(2)	
TIME (MIN.)	FEED COND	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	2.17	10	1.92	10	1.96	9.5	2.09	10.5	2.01	10	1.94	8	2
60	2.24	10	1.89	11	1.92	11	2.12	9	2.15	10.5	2.05	10	1.99
120	2.16	11	1.84	12	1.83	12.5	1.93	8.5	2.01	10	1.92	10	1.82

CALCULATED FLUX RATES AND REJECTIONS

	FLT - C(2)		FLT - B(2)		FLT - Q(2)		FLT - Q(2)		FLT - B(2)		FLT - C(2)	
TIME (MIN.)	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	0.6	11.5	0.6	9.7	0.6	3.7	0.6	7.4	0.6	10.6	0.5	7.8
60	0.6	15.6	0.7	14.3	0.7	5.4	0.5	4.0	0.6	8.5	0.6	11.2
120	0.7	14.8	0.7	15.3	0.8	10.6	0.5	6.9	0.6	11.1	0.6	15.7

(2) denotes second test performed with actual membrane.

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 345 kPa

TEMP.: 33 °C

NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S2 - 3, SITE E, FWKO & HTS

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 16.5	65	689	20	Recycle at 0 % VR
16.5 - 22	65	517	20	Recycle at 0 % VR
22 - 41.5	65	345	20	Recycle at 0 % VR
41.5 - 46.5	65	689	20	Recycle at 0 % VR
46.5 - 67	75	689	20	Recycle at 0 % VR
67 - 75.5	65	689	20	Recycle at 0 % VR
75.5 - 91	65	689	20	Recycle at 0 % VR
91 - 93		Clean With MC - 40		
93 - 111.5	65	689	20	Recycle at 0 % VR

FLUX DATA FROM TEST S2 - 3, SITE E, FWKO & HTS

DATE: FEBRUARY 12, 1987 MEMBRANES: FLT - C / FLT - B1 / THLT-C

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C) PERM. RATE (ml./min.)	TUBES 1 & 6 (FLT - C) COLOUR (APHA)	TUBES 2 & 5 (FLT - B1) PERM. RATE (ml./min.)	TUBES 2 & 5 (FLT - B1) COLOUR (APHA)	TUBES 3 & 4 (THLT-C) PERM. RATE (ml./min.)	TUBES 3 & 4 (THLT-C) COLOUR (APHA)
0.0	4500	30.0	800	N/A	N/A	94.0	200
1.0	4500	30.0	300	N/A	N/A	66.0	200
3.0	4500	30.0	150	N/A	N/A	49.0	200
15.0	4600	32.5	150	N/A	N/A	50.0	200
15.5	4600	32.5	150	N/A	N/A	48.0	200
16.5	4600	30.5	150	N/A	N/A	47.0	200
17.5	4600	22.0	150	N/A	N/A	34.5	200
18.50	4600	22.0	150	0.7	100	35.5	225
21.50	4600	22.0	150	N/A	N/A	37.0	200
22.00	4600	23.0	150	N/A	N/A	37.0	200
22.50	4600	15.0	150	N/A	N/A	23.5	200
23.50	4600	13.5	150	0.2	100	26.5	225
41.00	4600	15.0	150	N/A	N/A	32.0	200
41.50	4600	14.0	150	N/A	N/A	32.5	225
42.00	4600	30.0	150	N/A	N/A	57.0	250
42.50	5000	28.0	125	0.9	125	53.0	275
46.00	5500	25.6	150	0.9	125	43.6	250
46.50	5500	25.0	125	N/A	N/A	40.5	275
47.00	7500	28.0	150	N/A	N/A	42.0	275
47.50	7500	27.0	150	1.0	125	44.0	300
66.50	7500	19.3	150	N/A	N/A	26.5	275
67.00	7500	19.0	150	1.0	100	27.0	300
67.50	7500	16.7	150	N/A	N/A	22.3	300
68.50	7500	17.0	150	1.0	100	22.5	300
75.00	7500	15.2	150	N/A	100	20.2	300
75.50	7500	15.0	150	0.8	100	20.5	300
76.00	7500	15.0	150	N/A	N/A	19.5	300
76.50	7500	14.5	150	0.8	100	20.0	300
87.00	7500	14.8	150	N/A	N/A	19.5	300
87.50	7500	14.0	150	0.9	100	18.0	300

FLUX DATA FROM TEST #S2 - 3, SITE E, FWKO & HTS

DATE: FEBRUARY 12, 1987 MEMBRANES: FLT - C / FLT - B1 / THLT-C

		TUBES 1 & 6 (FLT - C)		TUBES 2 & 5 (FLT - B1)		TUBES 3 & 4 (THLT-C)	
TIME (hrs.)	FEED COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)
90.0	7500	14.3	150	N/A	N/A	19.3	300
90.5	7500	14.0	150	N/A	N/A	18.8	300
91.0	7500	13.5	125	0.9	100	18.5	275
93.3	7500	34.5	100	N/A	N/A	79.0	275
94.0	7500	34.5	100	1.1	175	61.0	275
95.0	7500	32.5	100	N/A	175	52.0	275
96.0	7500	32.5	100	0.9	175	48.5	275
111.0	7500	28.5	100	N/A	N/A	32.3	275
111.5	7500	27.7	100	0.7	175	31.3	275

FLUX RATES FOR TEST #S2 - 3, SITE E, FWKO & HTS WITH FLT - C / FLT - B1 / THLT - C MEMBRANES

TIME (hours)	FLT - C FLUX RATE m3/m2/D	FLT - B1 FLUX RATE m3/m2/D	THLT - C FLUX RATE m3/m2/D
0.0	1.80	N/A	5.64
1.0	1.80	N/A	3.96
3.0	1.80	N/A	2.94
15.0	1.95	N/A	3.00
15.5	1.95	N/A	2.88
16.5	1.83	N/A	2.82
17.5	1.32	N/A	2.07
18.50	1.32	0.04	2.13
21.50	1.32	N/A	2.22
22.00	1.38	N/A	2.22
22.50	0.90	N/A	1.41
23.50	0.81	0.01	1.59
41.00	0.90	N/A	1.92
41.50	0.84	N/A	1.95
42.00	1.80	N/A	3.42
42.50	1.68	0.05	3.18
46.00	1.54	0.05	2.62
46.50	1.50	N/A	2.43
47.00	1.68	N/A	2.52
47.50	1.62	0.06	2.64
66.50	1.16	N/A	1.59
67.00	1.14	0.06	1.62
67.50	1.00	N/A	1.34
68.50	1.02	0.06	1.35
75.00	0.91	N/A	1.21
75.50	0.90	0.05	1.23
76.00	0.90	N/A	1.17
76.50	0.87	0.05	1.20
87.00	0.89	N/A	1.17
87.50	0.84	0.05	1.08
90.0	0.86	N/A	1.16
90.5	0.84	N/A	1.13
91.0	0.81	0.05	1.11
93.3	2.07	N/A	4.74
94.0	2.07	0.06	3.66
95.0	1.95	N/A	3.12
96.0	1.95	0.05	2.91
111.0	1.71	N/A	1.94
111.5	1.66	0.04	1.88

SALT FLUX DATA FROM TEST #S2-3, SITE E, FWKO & HTS

DATE: FEBRUARY 12, 1987

MEMBRANE: FLT - C / FLT - B1 / THLT-C

RAW DATA

TIME (MIN.)	FEED COND	FLT - C		FLT - B1		THLT - C		THLT - C		FLT - B1		FLT - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	1.14	4	0.318	1	N/A	8.5	0.703	8.5	0.47	0.5	N/A	5	1.04
120	1.88	4	0.294	0.5	1.064	10	0.446	10.5	0.514	0.5	N/A	4	0.821

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	FLT - C		FLT - B1		THLT - C		THLT - C		FLT - B1		FLT - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	0.2	72.1	0.1	NA	0.5	38.3	0.5	58.8	0.03	N/A	0.3	8.8
120	0.2	84.4	0.03	43.4	0.6	76.3	0.6	72.7	0.03	N/A	0.2	56.3

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 345 kPa

TEMP.: 33 °C

NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S2 - 4, SITE E, FWKO & HTS, pH 9

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 26.5	65	689	20	Recycle at 0 % VR
26.5 - 46	65	517	20	Recycle at 0 % VR
46 - 119.5	65	345	20	Recycle at 0 % VR
119.5 - 123.5	65	345	20	Concentrate to 61.4 %VR
123.5 - 124.5	65	345	20	Rceycle at 61.4 % VR

FLUX DATA FROM TEST S2 - 4, SITE E, FWKO & HTS

DATE: FEBRUARY 17, 1987 MEMBRANES: FLT - C / FLT - B1 / THLT-C

		TUBES 1 & 6 (FLT - C)			TUBES 2 & 5 (FLT - B1)			TUBES 3 & 4 (THLT-C)				
TIME (hrs.)	FEED COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	TOTAL PERM. VOLUME (Litres)	% VOL. RED.
0.00	3200	27.5	125	N/A	N/A	N/A	N/A	105.0	500	N/A	N/A	N/A
1.00	3200	29.0	90	N/A	2.2	80	N/A	66.0	285	N/A	N/A	N/A
2.00	3250	28.6	90	N/A	2.0	75	N/A	61.8	285	N/A	N/A	N/A
3.00	3400	29.2	90	N/A	2.2	80	N/A	60.6	260	N/A	N/A	N/A
4.00	3450	27.8	95	N/A	2.0	65	N/A	58.0	245	N/A	N/A	N/A
5.00	N/A	25.3	N/A	N/A	2.4	N/A	N/A	55.9	N/A	N/A	N/A	N/A
6.00	3500	28.0	90	N/A	2.2	65	N/A	56.8	210	N/A	N/A	N/A
21.50	3500	28.0	90	N/A	N/A	65	N/A	N/A	175	N/A	N/A	N/A
24.00	3500	27.8	90	N/A	2.4	65	N/A	60.0	175	N/A	N/A	N/A
26.50	N/A	28.0	N/A	N/A	N/A	N/A	N/A	59.0	N/A	N/A	N/A	N/A
27.00	3500	21.0	90	N/A	N/A	N/A	N/A	44.7	180	N/A	N/A	N/A
28.00	N/A	23.0	N/A	N/A	1.7	N/A	N/A	47.0	180	N/A	N/A	N/A
30.00	3500	21.3	90	N/A	N/A	N/A	N/A	48.0	180	N/A	N/A	N/A
45.00	3500	21.5	90	N/A	1.7	65	N/A	54.0	180	N/A	N/A	N/A
46.00	3500	21.5	90	N/A	N/A	N/A	N/A	53.0	180	N/A	N/A	N/A
46.50	3500	13.0	90	N/A	N/A	N/A	N/A	34.0	180	N/A	N/A	N/A
48.00	3500	17.3	90	N/A	1.0	65	N/A	35.0	180	N/A	N/A	N/A
50.00	3500	13.5	90	N/A	N/A	N/A	N/A	37.0	180	N/A	N/A	N/A
53.00	3500	13.7	90	N/A	N/A	N/A	N/A	37.0	180	N/A	N/A	N/A
73.00	3500	13.0	90	N/A	N/A	N/A	N/A	41.5	180	N/A	N/A	N/A
96.00	3500	14.0	90	N/A	N/A	N/A	N/A	42.5	180	N/A	N/A	N/A
117.50	3500	13.5	90	N/A	N/A	N/A	N/A	40.5	180	N/A	N/A	N/A
119.50	3500	13.5	100	N/A	0.9	N/A	N/A	40.5	180	N/A	N/A	N/A
120.00	N/A	13.7	100	0.21	0.8	N/A	0.01	40.7	250	0.61	0.83	4.1
120.25	N/A	13.7	100	0.21	1.1	N/A	0.02	41.0	300	0.62	1.66	8.3
120.50	N/A	13.3	100	0.20	1.2	N/A	0.02	40.3	300	0.61	2.48	12.4
120.75	N/A	13.3	125	0.20	1.2	N/A	0.02	40.7	300	0.61	3.31	16.6
121.00	N/A	13.3	125	0.20	1.2	N/A	0.02	40.7	325	0.61	4.14	20.7
121.25	17500	13.5	150	0.20	1.2	N/A	0.02	40.3	350	0.61	4.96	24.8
121.50	17500	13.3	150	0.20	1.2	N/A	0.02	40.0	350	0.60	5.78	28.9

FLUX DATA FROM TEST S2 - 4, SITE E, FWKO & HTS

DATE: FEBRUARY 17, 1987 MEMBRANES: FLT - C / FLT - B1 / THLT-C

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C)			TUBES 2 & 5 (FLT - B1)			TUBES 3 & 4 (THLT-C)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
121.8	N/A	13.3	160	0.20	1.2	N/A	0.02	40.0	350	0.60	6.60	33.0
122.0	N/A	13.3	165	0.20	1.2	N/A	0.02	40.0	400	0.60	7.42	37.1
122.3	N/A	13.3	170	0.20	1.2	N/A	0.02	40.0	400	0.60	8.23	41.2
122.5	N/A	13.3	170	0.20	1.2	N/A	0.02	40.0	425	0.60	9.05	45.3
122.8	2750	13.3	170	0.20	1.2	N/A	0.02	39.7	425	0.60	9.86	49.3
123.0	N/A	13.3	175	0.20	1.2	N/A	0.02	39.7	450	0.60	10.68	53.4
123.3	2750	13.1	175	0.20	1.2	N/A	0.02	39.3	450	0.59	11.48	57.4
123.5	N/A	13.1	175	0.20	1.2	N/A	0.02	39.2	450	0.59	12.28	61.4
124.5	N/A	14.0	175	N/A	1.2	N/A	N/A	40.5	450	N/A	N/A	61.4

(2) denotes second test performed with actual membranes.

FLUX RATES FOT TEST #S2 - 4, SITE E, FWKO & HTS
WITH FLT - C / FLT - B1 / THLT - C MEMBRANES

TIME (hours)	FLT - C FLUX RATE m3/m2/D	FLT - B1 FLUX RATE m3/m2/D	THLT - C FLUX RATE m3/m2/D
0.00	1.65	N/A	6.30
1.00	1.74	0.13	3.96
2.00	1.72	0.12	3.71
3.00	1.75	0.13	3.64
4.00	1.67	0.12	3.48
5.00	1.52	0.14	3.35
6.00	1.68	0.13	3.41
21.50	1.68	N/A	N/A
24.00	1.67	0.15	3.60
26.50	1.68	N/A	3.54
27.00	1.26	N/A	2.68
28.00	1.38	0.10	2.82
30.00	1.28	N/A	2.88
45.00	1.29	0.10	3.24
46.00	1.29	N/A	3.18
46.50	0.78	N/A	2.04
48.00	1.04	0.06	2.10
50.00	0.81	N/A	2.22
53.00	0.82	N/A	2.22
73.00	0.78	N/A	2.49
96.00	0.84	N/A	2.55
117.50	0.81	N/A	2.43
119.50	0.81	0.05	2.43
120.00	0.82	0.05	2.44
120.25	0.82	0.06	2.46
120.50	0.80	0.07	2.42
120.75	0.80	0.07	2.44
121.00	0.80	0.07	2.44
121.25	0.81	0.07	2.42
121.50	0.80	0.07	2.40
121.8	0.80	0.07	2.40
122.0	0.80	0.07	2.40
122.3	0.80	0.07	2.40
122.5	0.80	0.07	2.40
122.8	0.80	0.07	2.38
123.0	0.80	0.07	2.38
123.3	0.79	0.07	2.36
123.5	0.78	0.07	2.35
124.5	0.84	0.07	2.43

(2) denotes second test performed with actual membranes

SALT FLUX DATA FROM TEST #S2-4, SITE E, FWKO & HTS

DATE: FEBRUARY 17, 1987 MEMBRANE: FLT - C / FLT - B1 /THLT-C

RAW DATA

TIME (MIN.)	FEED COND	FLT - C		FLT - B1		THLT - C		THLT - C		FLT - B1		FLT - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	1.73	4	0.378	N/A	0.63	9.5	0.468	13.75	0.491	N/A	0.967	2	0.512
120	1.81	4	0.255	0.365	N/A	9.5	0.448	14.5	0.621	1.78	N/A	3	0.371

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	FLT - C		FLT - B1		THLT - C		THLT - C		FLT - B1		FLT - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	0.2	78.2	N/A	63.6	0.6	72.9	0.8	71.6	N/A	44.1	0.1	70.4
180	0.2	85.9	0.02	N/A	0.6	75.2	0.9	65.7	0.1	N/A	0.2	79.5

(2) denotes second test performed with actual membrane.

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN. PRESSURE: 345 kPa

TEMP: 33 °C NaSO4 CONC.: 1,500 ppm

APPENDIX J

FLUX DATA FOR S3 TESTING

OPERATING CONDITIONS FOR TEST S3 - 1, SITE E, FWKO & HTS, pH 9

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 17.5	65	345	20	Recycle at 0 % VR
17.5 -23.25	65	345	20	Concentrate to 42.6 % VR
23.25		Clean With MC - 40		
22.5 - 28.75	65	345	20	Concentrate to 60 % VR
28.75 - 45	65	345	20	Recycle at 60 % VR
45 - 50.25	65	345	20	Concentrate to 87 % VR
50.25 - 70.5	75	345	20	Recycle at 87 % VR

FLUX DATA FROM TEST S3 - 1, SITE E, FWKO & HTS

DATE: FEBRUARY 23, 1987 MEMBRANES: FLT - C(2) / FLT - B1(2) / THLT - C(2)

		TUBES 1 & 6 (FLT - C(2))			TUBES 2 & 5 (FLT - B1(2))			TUBES 3 & 4 (THLT - C(2))			TOTAL	%
TIME (hrs.)	FEED COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. VOLUME (Litres)	VOL. RED.
0.00	N/A	14.0	500	N/A	N/A	N/A	N/A	70.8	700	N/A	N/A	N/A
0.50	N/A	15.3	400	N/A	N/A	N/A	N/A	61.3	600	N/A	N/A	N/A
1.00	N/A	15.0	250	N/A	N/A	N/A	N/A	59.3	550	N/A	N/A	N/A
16.00	10000	27.2	250	N/A	1.6	N/A	N/A	60.7	300	N/A	N/A	N/A
16.50	10000	27.3	250	N/A	N/A	N/A	N/A	60.5	300	N/A	N/A	N/A
17.50	10000	26.5	250	N/A	N/A	N/A	N/A	58.5	300	N/A	N/A	N/A
18.00	10000	26.0	275	0.39	1.6	N/A	0.02	56.7	300	0.85	1.26	3.1
18.25	10000	26.0	300	0.39	1.8	N/A	0.03	56.7	300	0.85	2.53	6.0
18.50	10000	26.0	325	0.39	1.9	N/A	0.03	56.5	300	0.85	3.80	8.7
18.78	10000	25.4	325	0.43	1.9	N/A	0.03	55.3	450	0.94	5.20	11.5
19.00	10000	25.8	350	0.34	1.9	N/A	0.03	55.5	450	0.72	6.28	13.6
19.25	10000	25.0	350	0.38	1.9	N/A	0.03	53.8	500	0.81	7.49	15.8
19.50	10000	25.0	350	0.38	1.9	N/A	0.03	54.0	500	0.81	8.71	17.9
19.75	10000	25.0	375	0.38	1.9	N/A	0.03	54.0	500	0.81	9.92	19.9
20.00	10000	24.7	375	0.37	1.9	N/A	0.03	53.0	500	0.80	11.11	21.7
20.25	10000	24.2	400	0.36	1.8	N/A	0.03	52.2	500	0.78	12.29	23.5
20.50	N/A	24.2	N/A	0.36	1.8	N/A	0.03	52.0	N/A	0.78	13.46	25.2
20.78	N/A	23.9	N/A	0.43	1.8	N/A	0.03	51.7	N/A	0.93	14.85	27.1
21.00	N/A	24.2	N/A	0.29	1.8	N/A	0.02	50.8	N/A	0.61	15.77	28.3
21.25	N/A	23.7	N/A	0.36	1.8	N/A	0.03	50.3	N/A	0.76	16.91	29.7
21.50	N/A	23.5	N/A	0.35	1.8	N/A	0.03	50.0	N/A	0.75	18.04	31.1
21.75	N/A	21.3	N/A	0.32	1.7	N/A	0.03	46.0	N/A	0.69	19.07	32.3
22.00	N/A	22.8	N/A	0.34	1.8	N/A	0.03	48.7	N/A	0.73	20.17	33.6
22.25	N/A	22.7	N/A	0.34	1.8	N/A	0.03	48.5	N/A	0.73	21.27	35.5
22.75	N/A	22.0	N/A	0.66	1.7	N/A	0.05	47.7	N/A	1.43	23.41	39.0
23.25	N/A	22.1	N/A	0.66	1.8	N/A	0.05	47.5	N/A	1.43	25.55	42.6
24.00	N/A	27.2	N/A	N/A	1.9	N/A	N/A	70.7	N/A	N/A	N/A	42.6
25.00	N/A	23.5	N/A	N/A	N/A	N/A	N/A	54.0	N/A	N/A	N/A	42.6
25.50	N/A	23.0	N/A	N/A	1.3	N/A	N/A	51.0	N/A	N/A	N/A	42.6
26.00	N/A	22.5	N/A	N/A	N/A	N/A	N/A	49.0	N/A	N/A	N/A	42.6

FLUX DATA FROM TEST S3 - 1, SITE E, FWKO & HTS

DATE: FEBRUARY 23, 1987 MEMBRANES: FLT - C / FLT - B / HLT

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FLT - C(2)) PERM. RATE (ml./min.)	TUBES 1 & 6 (FLT - C(2)) COLOUR (APHA)	TUBES 1 & 6 (FLT - C(2)) VOL. OF PERM. (Litres)	TUBES 2 & 5 (FLT - B1(2)) PERM. RATE (ml./min.)	TUBES 2 & 5 (FLT - B1(2)) COLOUR (APHA)	TUBES 2 & 5 (FLT - B1(2)) VOL. OF PERM. (Litres)	TUBES 3 & 4 (THLT - C(2)) PERM. RATE (ml./min.)	TUBES 3 & 4 (THLT - C(2)) COLOUR (APHA)	TUBES 3 & 4 (THLT - C(2)) VOL. OF PERM. (Litres)	TOTAL PERM. VOLUME (Litres)	% VOL. RED.
26.50	N/A	22.0	N/A	0.44	2.1	N/A	0.04	47.3	N/A	0.94	26.97	45.0
27.00	N/A	22.0	N/A	0.66	2.0	N/A	0.06	46.7	N/A	1.40	29.09	48.5
27.50	N/A	21.5	N/A	0.67	2.0	N/A	0.06	45.0	N/A	1.40	31.21	52.0
28.00	N/A	21.3	N/A	0.62	2.0	N/A	0.06	43.8	N/A	1.27	33.16	55.0
28.50	N/A	20.9	N/A	0.73	2.0	N/A	0.07	42.3	N/A	1.48	35.44	59.0
28.75	N/A	20.4	N/A	0.20	2.0	N/A	0.02	41.5	N/A	0.42	36.08	60.0
44.50	N/A	16.8	N/A	N/A	1.2	N/A	N/A	31.0	N/A	N/A	N/A	60.0
45.00	N/A	17.4	N/A	N/A	1.4	N/A	N/A	31.4	N/A	N/A	N/A	60.0
45.50	N/A	18.0	N/A	0.54	1.6	N/A	0.05	31.7	N/A	0.95	37.62	62.7
46.50	N/A	17.8	N/A	1.07	1.9	N/A	0.11	32	N/A	1.92	40.72	67.9
47.50	N/A	17.75	N/A	1.07	1.9	N/A	0.12	31.7	N/A	1.90	43.80	73.0
48.25	N/A	17.8	N/A	0.80	1.9	N/A	0.09	32.2	N/A	1.45	46.14	76.9
49.25	N/A	17.6	N/A	1.06	1.9	N/A	0.12	31.1	N/A	1.87	49.17	82.0
50.25	N/A	17.5	N/A	1.05	1.9	N/A	0.11	30.7	N/A	1.84	52.18	87.0
51.50	N/A	19.7	N/A	N/A	N/A	N/A	N/A	38	N/A	N/A	N/A	87.0
52.00	N/A	19.5	N/A	N/A	N/A	N/A	N/A	34.5	N/A	N/A	N/A	87.0
52.50	N/A	20	N/A	N/A	N/A	N/A	N/A	35.5	N/A	N/A	N/A	87.0
70.00	N/A	18.33	N/A	N/A	N/A	N/A	N/A	32.3	N/A	N/A	N/A	87.0
70.50	N/A	18.67	N/A	N/A	N/A	N/A	N/A	32	N/A	N/A	N/A	87.0

FLUX RATES FOR TEST #S3 - 1, SITE E, FWKO & HTS

TIME (hours)	FLT - C(2) FLUX RATE m3/m2/D	FLT - B1(2) FLUX RATE m3/m2/D	THLT - C(2) FLUX RATE m3/m2/D
0.00	0.84	N/A	4.25
0.50	0.92	N/A	3.68
1.00	0.90	N/A	3.56
16.00	1.63	0.10	3.64
16.50	1.64	N/A	3.63
17.50	1.59	N/A	3.51
18.00	1.56	0.09	3.40
18.25	1.56	0.11	3.40
18.50	1.56	0.11	3.39
18.78	1.52	0.11	3.32
19.00	1.55	0.12	3.33
19.25	1.50	0.11	3.23
19.50	1.50	0.11	3.24
19.75	1.50	0.11	3.24
20.00	1.48	0.11	3.18
20.25	1.45	0.11	3.13
20.50	1.45	0.11	3.12
20.78	1.44	0.11	3.10
21.00	1.45	0.11	3.05
21.25	1.42	0.11	3.02
21.50	1.41	0.11	3.00
21.75	1.28	0.10	2.76
22.00	1.37	0.11	2.92
22.25	1.36	0.11	2.91
22.75	1.32	0.10	2.86
23.25	1.32	0.11	2.85
24.00	1.63	0.11	4.24
25.00	1.41	N/A	3.24
25.50	1.38	0.08	3.06
26.00	1.35	N/A	2.94
26.50	1.32	0.13	2.84
27.00	1.32	0.12	2.80
27.50	1.29	0.12	2.70
28.00	1.28	0.12	2.63
28.50	1.25	0.12	2.54
28.75	1.22	0.12	2.49
44.50	1.01	0.07	1.86
45.00	1.04	0.08	1.88
45.50	1.08	0.10	1.90
46.50	1.07	0.11	1.92
47.50	1.07	0.11	1.90
48.25	1.07	0.11	1.93
49.25	1.06	0.11	1.87
50.25	1.05	0.11	1.84
51.50	1.18	N/A	2.28
52.00	1.17	N/A	2.07
52.50	1.20	N/A	2.13
70.00	1.10	N/A	1.94
70.50	1.12	N/A	1.92

OPERATING CONDITIONS FOR TEST S3 - 2, SITE E, FWKO & HTS

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 2	65	345	20	Recycle at 0 % VR
2 - 9	65	345	20	Concentrate to 84.1 % VR
9 - 24.25	65	345	20	Recycle at 84.1 % VR
24.25 - 28.5	75	345	20	Recycle at 84.1 % VR
28.5 - 31.5	85	345	20	Recycle at 84.1 % VR

FLUX DATA FROM TEST S3 - 2, SITE E, FWKO & HTS

DATE: MARCH 3, 1987

MEMBRANES: FLT - C(3) /THLT - C1 / THLT - C(3)

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (FTL - C(3)) PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	TUBES 2 & 5 (THLT - C1) PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	TUBES 3 & 4 (THLT - C(3)) PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	TOTAL PERM. VOLUME (Litres)	% VOL. RED.
0.00	2500	15.3	500	N/A	106.3	850	N/A	59.0	700	N/A	N/A	N/A
0.50	N/A	15.5	N/A	N/A	94.0	N/A	N/A	56.5	N/A	N/A	N/A	N/A
1.00	2500	15.1	425	N/A	84.0	550	N/A	53.0	500	N/A	N/A	N/A
2.00	2500	14.5	375	N/A	72.0	450	N/A	48.5	500	N/A	N/A	N/A
2.50	N/A	14.9	N/A	0.22	67.7	N/A	1.02	46.7	N/A	0.70	1.94	4.6
2.75	N/A	14.8	N/A	0.22	66.7	N/A	1.00	45.9	N/A	0.69	3.85	8.8
3.00	3000	14.9	375	0.22	66.0	450	0.99	45.9	500	0.69	5.75	12.6
3.25	N/A	14.7	N/A	0.22	63.0	N/A	0.95	44.0	N/A	0.66	7.58	15.9
3.50	N/A	14.5	N/A	0.22	61.5	N/A	0.92	43.5	N/A	0.65	9.37	18.9
3.75	N/A	14.5	N/A	0.22	60.0	N/A	0.90	43.1	N/A	0.65	11.13	22.3
4.00	5000	14.6	375	0.22	58.7	425	0.88	43.0	400	0.65	12.88	25.8
4.25	N/A	14.3	N/A	0.21	56.3	N/A	0.85	42.3	N/A	0.64	14.57	29.1
4.50	N/A	14.3	N/A	0.21	55.3	N/A	0.83	41.0	N/A	0.62	16.23	32.5
5.00	6000	14.3	325	0.43	53.3	425	1.60	41.3	400	1.24	19.50	39.0
5.50	N/A	14.2	N/A	0.43	50.7	N/A	1.52	40.3	N/A	1.21	22.65	45.3
6.00	N/A	13.9	325	0.42	48.0	375	1.44	39.0	400	1.17	25.68	51.4
6.50	6200	13.8	N/A	0.42	45.7	N/A	1.37	38.5	N/A	1.16	28.62	57.3
7.00	N/A	13.5	275	0.41	43.7	390	1.31	37.3	400	1.12	31.46	62.9
7.58	6800	13.6	N/A	0.48	41.4	N/A	1.45	36.6	N/A	1.28	34.66	69.3
8.00	N/A	13.4	325	0.34	40.0	400	1.00	36.0	400	0.90	36.90	73.8
8.50	9500	13.3	N/A	0.40	38.3	N/A	1.15	35.3	N/A	1.06	39.51	79.0
9.00	N/A	13.3	375	0.40	37.0	450	1.11	34.7	450	1.04	42.06	84.1
14.25	22500	12.8	400	N/A	30.0	400	N/A	32.0	400	N/A	N/A	84.1
23.35	22500	11.3	400	N/A	31.0	425	N/A	30.5	425	N/A	N/A	84.1
24.25	22500	13.0	N/A	N/A	31.5	N/A	N/A	32.0	N/A	N/A	N/A	84.1
25.75	N/A	13.5	N/A	N/A	37.5	N/A	N/A	35.5	N/A	N/A	N/A	84.1
26.75	N/A	13.6	N/A	N/A	39.3	N/A	N/A	37.3	N/A	N/A	N/A	84.1
28.50	N/A	13.0	N/A	N/A	40.5	N/A	N/A	37.5	N/A	N/A	N/A	84.1
29.50	N/A	15.5	N/A	N/A	50.0	N/A	N/A	44.0	N/A	N/A	N/A	84.1
30.50	N/A	17.3	400	N/A	56.5	425	N/A	47.5	425	N/A	N/A	84.1
31.50	N/A	17.8	400	N/A	59.0	425	N/A	48.0	425	N/A	N/A	84.1

FLUX RATES FOR TEST #S3 - 2, SITE E, FWKO & HTS

TIME (hours)	FLT - C(3) FLUX RATE m3/m2/D	THLT - C1 FLUX RATE m3/m2/D	THLT - C(3) FLUX RATE m3/m2/D
0.00	0.92	6.38	3.54
0.50	0.93	5.64	3.39
1.00	0.90	5.04	3.18
2.00	0.87	4.32	2.91
2.50	0.89	4.06	2.80
2.75	0.89	4.00	2.75
3.00	0.89	3.96	2.75
3.25	0.88	3.78	2.64
3.50	0.87	3.69	2.61
3.75	0.87	3.60	2.59
4.00	0.88	3.52	2.58
4.25	0.86	3.38	2.54
4.50	0.86	3.32	2.46
5.00	0.86	3.20	2.48
5.50	0.85	3.04	2.42
6.00	0.83	2.88	2.34
6.50	0.83	2.74	2.31
7.00	0.81	2.62	2.24
7.58	0.81	2.48	2.19
8.00	0.80	2.40	2.16
8.50	0.80	2.30	2.12
9.00	0.80	2.22	2.08
14.25	0.77	1.80	1.92
23.35	0.68	1.86	1.83
24.25	0.78	1.89	1.92
25.75	0.81	2.25	2.13
26.75	0.82	2.36	2.24
28.50	0.78	2.43	2.25
29.50	0.93	3.00	2.64
30.50	1.04	3.39	2.85
31.50	1.07	3.54	2.88

SALT FLUX DATA FROM TEST #S3-2, SITE E, FWKO & HTS

DATE: MARCH 3, 1987

MEMBRANE: FLT - C(3) / THLT - C1 /THLT - C(3)

RAW DATA

TIME (MIN.)	FEED COND	FLT - C(3)		THLT - C1		THLT - C(3)		THLT - C(3)		THLT - C1		FLT - C(3)	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	1.97	8	0.454	37.5	0.641	16	0.472	22	0.62	27	0.64	2.8	0.595
60	1.97	8	0.456	40	0.805	15	0.605	21	0.759	28	0.769	2.4	0.461

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	FLT - C(3)		THLT - C1		THLT - C(3)		THLT - C(3)		THLT - C1		FLT - C(3)	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	1.0	77.0	4.5	67.5	1.9	76.0	2.6	68.5	3.2	67.5	0.3	69.8
180	1.0	76.9	4.8	59.1	1.8	69.3	2.5	61.5	3.4	61.0	0.3	76.6

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 345 kPa

TEMP.: 33 °C

NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S3 - 3, SITE C, Skim Tank

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 6	65	345	20	Recycle at 0 % VR
6 - 7.3	75	345	20	Recycle at 0 % VR
7.3 - 8.5	85	345	20	Recycle at 0 % VR
8.5 - 9.5	80	345	20	Recycle at 0 % VR

FLUX DATA FROM TEST S3 - 3, SITE C, Skim Tank

DATE: MARCH 21, 1987 MEMBRANES: THLT-C/HLT-C/FLT-C

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (THLT - C)			TUBES 2 & 5 (HLT-SC)			TUBES 3 & 4 (FLT-C)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
0.0	1900	51.0	820	0.00	99.0	650	0.00	25.0	450	0.00	0.00	0
0.5	N/A	39.0	N/A	0.00	78.3	N/A	0.00	23.3	N/A	0.00	0.00	0
1.0	N/A	40.5	600	0.00	82.0	500	0.00	25.5	350	0.00	0.00	0
2.0	2250	36.0	400	0.00	72.0	375	0.00	27.0	250	0.00	0.00	0
2.3	N/A	31.0	N/A	0.00	63.0	N/A	0.00	24.5	N/A	0.00	0.00	0
3.0	N/A	25.0	325	0.00	55.0	325	0.00	25.5	225	0.00	0.00	0
4.5	2500	25.5	225	0.00	46.0	290	0.00	25.5	175	0.00	0.00	0
5.0	N/A	24.7	250	0.00	43.3	220	0.00	25.6	185	0.00	0.00	0
6.0	2375	25.0	225	0.00	41.0	200	0.00	26.5	140	0.00	0.00	0
6.5	N/A	29.3	N/A	0.00	47.0	N/A	0.00	32.0	N/A	0.00	0.00	0
7.0	2000	28.5	235	0.00	45.5	260	0.00	32.0	200	0.00	0.00	0
7.3	N/A	29.0	N/A	0.00	45.5	N/A	0.00	32.5	N/A	0.00	0.00	0
7.8	N/A	36.0	N/A	0.00	55.6	N/A	0.00	43.6	N/A	0.00	0.00	0
8.3	2750	36.0	275	0.00	55.0	360	0.00	48.5	210	0.00	0.00	0
8.5	N/A	36.0	N/A	0.00	54.0	N/A	0.00	50.0	N/A	0.00	0.00	0
9.5	N/A	35.0	N/A	0.00	49.0	N/A	0.00	48.0	N/A	0.00	0.00	0

FLUX RATES FOR TEST #S3 - 3, SITE C, Skim Tank WITH THLT - C / HLT - C / FLT - C MEMBRANES

TIME (hours)	THLT-C FLUX RATE m3/m2/D	HLT-SC FLUX RATE m3/m2/D	FLT-C FLUX RATE m3/m2/D
0.0	3.06	5.94	1.50
0.5	2.34	4.70	1.40
1.0	2.43	4.92	1.53
2.0	2.16	4.32	1.62
2.3	1.86	3.78	1.47
3.0	1.50	3.30	1.53
4.5	1.53	2.76	1.53
5.0	1.48	2.60	1.54
6.0	1.50	2.46	1.59
6.5	1.76	2.82	1.92
7.0	1.71	2.73	1.92
7.3	1.74	2.73	1.95
7.8	2.16	3.34	2.62
8.3	2.16	3.30	2.91
8.5	2.16	3.24	3.00
9.5	2.10	2.94	2.88

SALT FLUX DATA FROM TEST #S3-3, SITE C, Skim Tank

DATE: MARCH 20, 1987

MEMBRANE: THLT - C / HLT - SC / FLT-C

RAW DATA

TIME (MIN.)	FEED COND	THLT - C		HLT - SC		FLT - C		FLT - C		HLT - SC		THLT - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	1.814	25	0.965	14.5	0.542	7.25	0.692	6	0.494	14	0.444	9.5	1.33
60	1.77	21	0.57	20	0.304	7.5	0.447	6	0.478	18	0.321	5.5	0.596

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	THLT - C		HLT - SC		FLT - C		FLT - C		HLT - SC		THLT - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	3.0	46.8	1.7	70.1	0.9	61.9	0.7	72.8	1.7	75.5	1.1	26.7
60	2.5	67.8	2.4	82.8	0.9	74.7	0.7	73.0	2.2	81.9	0.7	66.3

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 345 kPa

TEMP.: 33 °C

NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S3 - 4, SITE C, Skim Tank, pH 9

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 5	65	345	20	Recycle at 0 % VR
5 - 6.5	75	345	20	Recycle at 0 % VR
6.5 - 8	85	345	20	Recycle at 0 % VR
8 - 24	65	345	20	Recycle at 0 % VR
24 - 25	65	345	25	Recycle at 0 % VR
25 - 26	65	345	15	Recycle at 0 % VR
26 - 27	65	345	20	Recycle at 0 % VR
27 - 28	65	517	20	Recycle at 0 % VR
28 - 30	65	689	20	Recycle at 0 % VR
30 - 30.5	65	345	20	Recycle at 0 % VR

FLUX DATA FROM TEST S3 - 4, SITE C, Skim Tank, pH 9.0

DATE: MARCH 26, 1987 MEMBRANES: HLT-SC, FLT-C & THLT-C

		TUBES 1 & 6 (HLT - SC)			TUBES 2 & 5 (FLT - C)			TUBES 3 & 4 (THLT - C)			TOTAL	
TIME (hrs.)	FEED COLOUR (APHA)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. VOLUME (Litres)	% VOL. RED.
0.0	3000	97.0	1100	0.00	29.2	250	0.00	101.5	700	0.00	0.00	0
0.5	NA	81.0	NA	0.00	34.5	NA	0.00	55.3	NA	0.00	0.00	0
1.0	3000	67.0	650	0.00	37.5	250	0.00	61.0	350	0.00	0.00	0
1.5	NA	60.0	NA	0.00	38.0	NA	0.00	49.0	NA	0.00	0.00	0
2.5	3000	39.5	500	0.00	37.0	150	0.00	36.0	375	0.00	0.00	0
3.0	NA	35.0	NA	0.00	36.5	NA	0.00	32.5	NA	0.00	0.00	0
4.0	3500	31.5	350	0.00	36.5	150	0.00	30.5	375	0.00	0.00	0
4.5	NA	30.0	NA	0.00	36.0	NA	0.00	28.5	NA	0.00	0.00	0
5.0	3500	29.5	350	0.00	37.0	150	0.00	28.0	350	0.00	0.00	0
5.5	NA	34.3	NA	0.00	43.0	NA	0.00	33.5	NA	0.00	0.00	0
6.0	3500	33.0	350	0.00	42.0	125	0.00	32.3	350	0.00	0.00	0
6.5	NA	32.3	NA	0.00	42.5	NA	0.00	31.0	NA	0.00	0.00	0
7.0	NA	38.0	NA	0.00	51.0	NA	0.00	41.0	NA	0.00	0.00	0
7.5	3500	37.0	425	0.00	56.0	150	0.00	35.0	400	0.00	0.00	0
8.0	NA	35.0	NA	0.00	55.0	NA	0.00	34.0	NA	0.00	0.00	0
9.0	3500	23.0	350	0.00	39.5	125	0.00	20.5	350	0.00	0.00	0
10.0	NA	25.0	NA	0.00	42.5	NA	0.00	24.0	NA	0.00	0.00	0
23.0	NA	16.0	NA	0.00	34.0	NA	0.00	15.5	NA	0.00	0.00	0
23.5	3500	16.0	350	0.00	32.5	125	0.00	15.5	325	0.00	0.00	0
24.0	NA	15.5	NA	0.00	33.0	NA	0.00	15.5	350	0.00	0.00	0
24.5	NA	14.5	NA	0.00	32.5	NA	0.00	14.8	NA	0.00	0.00	0
25.0	3500	15.0	350	0.00	32.5	125	0.00	15.5	350	0.00	0.00	0
25.5	3500	15.3	350	0.00	31.0	125	0.00	16.5	350	0.00	0.00	0
26.0	3500	14.5	350	0.00	30.0	125	0.00	15.5	350	0.00	0.00	0
26.5	3500	14.5	350	0.00	29.5	125	0.00	16.0	350	0.00	0.00	0
27.0	3500	14.5	350	0.00	30.0	125	0.00	15.5	350	0.00	0.00	0
27.5	3500	21.5	325	0.00	46.5	125	0.00	24.0	350	0.00	0.00	0
28.0	3500	20.0	325	0.00	45.5	125	0.00	22.5	350	0.00	0.00	0
29.0	3500	24.5	325	0.00	53.0	125	0.00	25.0	350	0.00	0.00	0
29.5	3500	21.5	325	0.00	46.5	125	0.00	24.5	350	0.00	0.00	0
30.0	3500	21.0	325	0.00	43.0	125	0.00	24.0	350	0.00	0.00	0
30.5	3500	9.5	325	0.00	21.0	125	0.00	12.0	350	0.00	0.00	0

FLUX RATES FOR TEST #S3 - 4, SITE C, Skim Tank, pH 9.0 WITH HLT-SC, FLT-C & THLT-C MEMBRANES

TIME (hours)	HLT-SC FLUX RATE m3/m2/D	FLT-C FLUX RATE m3/m2/D	THLT-C FLUX RATE m3/m2/D
0.0	5.8	1.8	6.1
0.5	4.9	2.1	3.3
1.0	4.0	2.3	3.7
1.5	3.6	2.3	2.9
2.5	2.4	2.2	2.2
3.0	2.1	2.2	2.0
4.0	1.9	2.2	1.8
4.5	1.8	2.2	1.7
5.0	1.8	2.2	1.7
5.5	2.1	2.6	2.0
6.0	2.0	2.5	1.9
6.5	1.9	2.6	1.9
7.0	2.3	3.1	2.5
7.5	2.2	3.4	2.1
8.0	2.1	3.3	2.0
9.0	1.4	2.4	1.2
10.0	1.5	2.6	1.4
23.0	1.0	2.0	0.9
23.5	1.0	2.0	0.9
24.0	0.9	2.0	0.9
24.5	0.9	2.0	0.9
25.0	0.9	2.0	0.9
25.5	0.9	1.9	1.0
26.0	0.9	1.8	0.9
26.5	0.9	1.8	1.0
27.0	0.9	1.8	0.9
27.5	1.3	2.8	1.4
28.0	1.2	2.7	1.4
29.0	1.5	3.2	1.5
29.5	1.3	2.8	1.5
30.0	1.3	2.6	1.4
30.5	0.6	1.3	0.7

SALT FLUX DATA FROM TEST #S3-4, SITE C, Skim Tank

DATE: MARCH 25, 1987

MEMBRANE: HLT - SC / FLT - C / THLT-C

RAW DATA

TIME (MIN.)	FEED COND	HLT - SC		FLT - C		THLT - C		THLT - C		FLT - C		HLT - SC	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	1.709	48	0.942	9.25	0.48	83	1.244	60	1.158	8.5	0.605	26.5	1.027
60	1.629	42.5	0.95	8.5	0.417	66.5	1.134	49	1.056	8	0.528	28.25	1.022

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	HLT - SC		FLT - C		THLT - C		THLT - C		FLT - C		HLT - SC	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	5.8	44.9	1.1	71.9	10.0	27.2	7.2	32.2	1.0	64.6	3.2	39.9
60	5.1	41.7	1.0	74.4	8.0	30.4	5.9	35.2	1.0	67.6	3.4	37.3

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN.

PRESSURE: 345 kPa

TEMP.: 33 °C

NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S3 - 5, SITE C, Skim Tank

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 2	65	345	20	Recycle at 0 % VR
2 - 12.3	65	345	20	Concentrate to 89 % VR
12.3 - 25.5	65	345	20	Recycle at 89 % VR

FLUX DATA FROM TEST S3 - 5, SITE C, Skim Tank

DATE: MARCH 28, 1987 MEMBRANES: THLT-C, FLT-C & HLT-SC

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (THLT-C)			TUBES 2 & 5 (FLT-C)			TUBES 3 & 4 (HLT-SC)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
0.0	2500	82.0	850	0.00	18.5	450	0.00	88.0	600	0.00	0.00	0.00%
0.5	2500	74.0	800	0.00	19.0	425	0.00	78.0	550	0.00	0.00	0.00%
1.0	2500	67.0	750	0.00	20.0	400	0.00	73.0	500	0.00	0.00	0.00%
1.5	2500	58.0	700	0.00	21.0	400	0.00	67.5	500	0.00	0.00	0.00%
2.0	2500	52.0	650	0.00	21.0	350	0.00	65.5	475	0.00	0.00	0.00%
2.3	2500	54.3	600	0.82	20.8	300	0.31	62.7	425	0.94	2.07	3.45%
2.5	2500	50.7	600	0.76	20.3	300	0.31	59.0	425	0.89	4.02	6.70%
2.8	3000	48.0	575	0.72	20.0	300	0.30	56.3	450	0.85	5.88	9.80%
3.0	3000	45.1	550	0.68	20.0	300	0.30	52.7	500	0.79	7.65	12.75%
3.5	3500	42.7	550	1.28	19.5	300	0.59	50.5	500	1.52	11.03	18.38%
4.0	3500	39.7	550	1.19	19.3	300	0.58	46.0	500	1.38	14.18	23.63%
4.5	3100	37.3	575	1.12	19.3	350	0.58	44.1	485	1.32	17.20	28.67%
5.0	2750	35.7	600	1.07	19.6	400	0.59	41.5	475	1.25	20.10	33.51%
5.5	3875	33.8	560	1.03	19.3	385	0.59	39.3	480	1.20	22.92	38.21%
6.5	5000	32.3	525	1.94	20.8	375	1.25	37.3	485	2.24	28.35	47.26%
7.5	5000	30.0	500	1.80	22.0	335	1.32	34.2	430	2.05	33.52	55.87%
8.5	5000	26.8	475	1.61	22.8	285	1.37	30.3	375	1.82	38.32	63.87%
9.5	NA	23.7	NA	1.42	23.3	NA	1.40	26.5	NA	1.59	42.73	71.22%
10.5	8000	21.6	425	1.30	24.0	250	1.44	24.1	310	1.45	46.91	78.18%
11.5	9000	20.0	425	1.20	24.0	225	1.44	22.3	300	1.34	50.89	84.82%
12.3	NA	19.1	NA	0.77	24.0	NA	0.96	21.3	NA	0.85	53.46	89.11%
25.0	9200	17.0	400	0.00	25.5	225	0.00	15.0	325	0.00	53.46	89.11%
25.5	9200	16.0	400	0.00	25.0	225	0.00	14.0	325	0.00	53.46	89.11%

FLUX RATES FOR TEST #S3 - 5, SITE C, Skim Tank
WITH THLT-C, FLT-C & HLT-SC MEMBRANES

TIME (hours)	THLT-C FLUX RATE m3/m2/D	FLT-C FLUX RATE m3/m2/D	HLT-SC FLUX RATE m3/m2/D
0.0	4.9	1.1	5.3
0.5	4.4	1.1	4.7
1.0	4.0	1.2	4.4
1.5	3.5	1.3	4.1
2.0	3.1	1.3	3.9
2.3	3.3	1.2	3.8
2.5	3.0	1.2	3.5
2.8	2.9	1.2	3.4
3.0	2.7	1.2	3.2
3.5	2.6	1.2	3.0
4.0	2.4	1.2	2.8
4.5	2.2	1.2	2.6
5.0	2.1	1.2	2.5
5.5	2.0	1.2	2.4
6.5	1.9	1.2	2.2
7.5	1.8	1.3	2.1
8.5	1.6	1.4	1.8
9.5	1.4	1.4	1.6
10.5	1.3	1.4	1.4
11.5	1.2	1.4	1.3
12.3	1.1	1.4	1.3
25.0	1.0	1.5	0.9
25.5	1.0	1.5	0.8

SALT FLUX DATA FROM TEST #S3-5, SITE C, Skim Tank

DATE: MARCH 27, 1987 MEMBRANE: THLT - C / FLT - C / HLT- SC

RAW DATA

TIME (MIN.)	FEED COND	THLT - C		FLT - C		HLT - SC		HLT - SC		FLT - C		THLT - C	
		RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho	RATE ml./min.	COND. umho
0	2.08	30	1.11	6.5	0.858	20.5	0.395	18.5	0.505	5.25	0.7	22.5	1.009
60	2.12	27	1.03	5.5	0.656	23	0.396	22	0.396	5	0.628	23	0.94

CALCULATED FLUX RATES AND REJECTIONS

TIME (MIN.)	THLT - C		FLT - C		HLT - SC		HLT - SC		FLT - C		THLT - C	
	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.	FLUX m3/m2/D	% REJECT.
0	3.6	46.6	0.8	58.8	2.5	81.0	2.2	75.7	0.6	66.3	2.7	51.5
60	3.2	51.4	0.7	69.1	2.8	81.3	2.6	81.3	0.6	70.4	2.8	55.7

OPERATING CONDITIONS

FLOW RATE: 20 L/MIN. PRESSURE: 345 kPa

TEMP.: 33 °C NaSO4 CONC.: 1,500 ppm

OPERATING CONDITIONS FOR TEST S3 - 6, SITE C, Skim Tank

Elapsed Time (hours)	Operating Temperature (°C)	Trans-Membrane Pressure (kPa)	Flow Through Tube (L / min)	Concentration
0 - 1.5	65	345	20	Recycle at 0 % VR
1.5 - 13.75	65	345	20	Concentrate to 87 % VR
13.75 - 25	65	345	20	Recycle at 87 % VR

FLUX DATA FROM TEST S3 - 6, SITE C, Skim Tank

DATE: MARCH 29, 1987 MEMBRANES: THLT-C(2), FLT-C(2) & HLT-SC(2)

TIME (hrs.)	FEED COLOUR (APHA)	TUBES 1 & 6 (THLT-C)			TUBES 2 & 5 (FLT-C)			TUBES 3 & 4 (HLT-SC)			TOTAL PERM. VOLUME (Litres)	% VOL. RED.
		PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)	PERM. RATE (ml./min.)	COLOUR (APHA)	VOL. OF PERM. (Litres)		
0.00	2,700	128.0	1000	0.00	35.0	500	0.00	134.0	700	0.00	0.00	N/A
0.50	NA	85.0	NA	0.00	41.0	NA	0.00	94.0	NA	0.00	0.00	N/A
1.00	NA	71.0	NA	0.00	41.5	NA	0.00	79.5	NA	0.00	0.00	N/A
1.50	2,700	68.5	650	0.00	44.5	375	0.00	72.0	550	0.00	0.00	N/A
2.50	3,500	55.3	800	0.83	43.7	700	0.66	57.3	700	0.86	2.35	5.40
2.75	NA	50.7	NA	0.76	41.7	NA	0.63	52.7	NA	0.79	4.52	10.15
3.25	3,500	46.3	700	1.39	39.5	650	1.19	46.7	750	1.40	8.50	17.52
4.25	NA	40.6	NA	2.44	37.3	NA	2.24	40.0	NA	2.40	15.57	28.03
5.25	4,200	35.0	750	2.28	35.8	650	2.33	33.3	750	2.17	22.34	37.20
6.25	NA	31.3	NA	1.72	35.3	NA	1.94	28.7	NA	1.58	27.58	45.97
7.25	5,000	25.5	650	1.53	31.1	600	1.87	22.7	650	1.36	32.34	53.90
8.25	NA	21.4	NA	1.27	27.7	NA	1.64	18.4	NA	1.09	36.32	60.50
11.17	9,000	17.5	550	2.99	25.1	500	4.30	14.1	475	2.41	46.02	76.70
12.50	N/A	14.8	500	1.26	23.3	450	1.98	10.7	400	0.92	50.17	83.60
13.75	14,000	13.8	500	0.65	22.6	450	1.06	9.6	400	0.46	52.33	87.20
22.00	15,000	14.0	500	N/A	21.5	400	N/A	8.0	350	N/A	N/A	N/A
23.00	15,000	13.0	500	N/A	21.5	400	N/A	9.0	350	N/A	N/A	N/A
25.00	15,000	13.0	500	N/A	21.5	400	N/A	9.0	350	N/A	N/A	N/A

FLUX RATES FOR TEST #S3 - 6, SITE C, Skim Tank
WITH THLT-C(2), FLT-C(2) & HLT-SC(2) MEMBRANES

TIME (hours)	THLT-C FLUX RATE m3/m2/D	FLT-C FLUX RATE m3/m2/D	HLT-SC FLUX RATE m3/m2/D
0.00	7.68	2.10	8.04
0.50	5.10	2.46	5.64
1.00	4.26	2.49	4.77
1.50	4.11	2.67	4.32
2.50	3.32	2.62	3.44
2.75	3.04	2.50	3.16
3.25	2.78	2.37	2.80
4.25	2.44	2.24	2.40
5.25	2.10	2.15	2.00
6.25	1.88	2.12	1.72
7.25	1.53	1.87	1.36
8.25	1.28	1.66	1.10
11.17	1.05	1.51	0.84
12.50	0.89	1.40	0.64
13.75	0.83	1.36	0.58
22.00	0.84	1.29	0.48
23.00	0.78	1.29	0.54
25.00	0.78	1.29	0.54

APPENDIX K

DETAILED COST BREAKDOWN
FOR CONVENTIONAL PROCESS

DESIGN PARAMETERS

CONVENTIONAL TREATMENT SYSTEM

SKIM TANK

- Retention time 10 hours
- Flow 350 US.gpm
- Tank is equipped with surface skim and bottom solids removal
- Process includes a Skim Tank, a Skim Oil Storage Tank, a Chemical Storage Tank and a Transfer Pump
- Chemical Dosage is 10 ppm of polyelectrolyte at $13.25/gal
- Two thirds of one shift per day average labour for operation
- Does not include treatment of oil skim or solids

INDUCED GAS FLOATATION

- Flow 350 US.gpm
- Wemco #66 IGF unit is used
- Natural Gas is used as floatation gas
- Includes 21,000 gallon Feed Storage Tank, 21,000 gallon Float Storage Tank, Chemical Storage Tank and Transfer Pump
- Chemical Dosage is 5 ppm of high molecular weight polymer at $22.71/gallon
- Two thirds of one shift per day average labour for operation
- Does not include treatment of oil float

SAND FILTER

- Two 8' diameter Eimco Pressurized Sand Filters
- Price includes 42,000 gallon feed storage tank and pump

- Chemical dosage is 50 ppm of polyelectrolyte at $13.25/gal.
- Two thirds of one shift per day average labour for operation and backwash etc.
- Does not include treatment of backwash water

GENERAL

- Electrical rate used in all costing is 3.66 cents/KWH (from EMR Energy Stats Handbook)
- Labour rate used includes salary and overhead at $100,900/yr/shift

CONVENTIONAL OIL REMOVAL PROCESS
CAPITAL COSTS OF INDIVIDUAL COMPONENTS

Skim Tank System	$161,432
IGF System	$193,300
Sand Filter System	$103,300
TOTAL PROCESS COSTS	$458,032

CONVENTIONAL OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$458,032		
Shipping Charges	$36,643		
Installation of Equipment	$91,606		
Foundations	$77,865		
Instruments	$64,124		
Piping	$114,508		
Insulation	$77,865		
Electrical	$91,606		
Building and Structures	$45,803		
Services	$54,964		
Misc.	$45,803		
TOTAL DIRECT COSTS		$1,158,821	
Construction and Field Expences	$115,882		
Engineering Expences	$92,706		
Contractors Fees	$68,370		
Contingencies	$136,741		
TOTAL INDIRECT EXPENCES		$413,699	
TOTAL COSTS			$1,572,520

CONVENTIONAL OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS (Demulsifying Chemicals)		
Skim Tank (10 ppm @ $13.25/gal.)	$24,181	
IGF (5 ppm @ $22.71/gal.)	$20,723	
Sand Filter (50 ppm @ $13.25/gal.)	$120,906	
LABOUR (equipment supervision and filter backwash)		
Skim Tank (2/3 shift / day, @$100,937/shift/yr.)	$67,291	
IGF (2/3 shift / day, @$100,937/shift/yr.)	$67,291	
Sand Filter (2/3 shift / day, @$100,937/shift/yr.)	$67,291	
ENERGY		
Skim Tank (15 HP)		
IGF (35 HP)		
Sand Filter (5 HP)		
(55 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$13,150	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (15 % of other expences)	$53,498	
TOTAL OPERATING COSTS		$434,331

APPENDIX L

DETAILED COST BREAKDOWN FOR MEMBRANE PROCESSES

DESIGN PARAMETERS

MEMBRANE TREATMENT SYSTEMS

ULTRAFILTRATION MEMBRANE EQUIPMENT

- Flux rates of 100, 75, and 50 gfd have been costed separately
- Three, four, and six individual systems each with 1,740 ft^2 of membrane area are required for the assumed flux rates of 100, 75, and 50 gfd
- System includes explosion proof SS Pump, all plumbing and hardware, explosion proof electronic controls, membranes, labour for assembly, wash system, manufacturer overhead and fee, and engineering expenses
- Feed and bleed design, assuming a 10 fold concentration factor
- Operating pressure is 100 psi and operating temperature is assumed to be 65°C or higher
- Does not include treatment of concentrate which is assumed to be recycled back to FWKO or disposed of
- Three membrane module costs have been used and costed separately
- The high module cost system represents currently available one half inch modules with fiber reinforced plastic (FRP) support tubes and membranes at \$56.29 ft^2 and replacement membranes at \$14.45/ft^2
- Medium cost modules represent the expected price of disposable membranes and modules of a one half inch tubular configuration. The assumed cost is \$25/ft^2 of membrane.
- The low cost modules represent the expected price of disposable membranes and modules of a small tube (2 - 3 mm diameter)

configuration. The assumed cost is \$15/ft^2 of membrane.

- All membrane systems employ ZENON's high temperature, fouling resistant CHP membrane.

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	100	
Number of Systems	3	
Membrane Cost	High	
COST PER SYSTEM		$230,603
TOTAL COST		$691,810

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$691,810		
Shipping Charges	$34,590		
Installation of Equipment	$55,345		
Foundations	$34,590		
Instruments	$41,509		
Piping	$55,345		
Insulation	$69,181		
Electrical	$83,017		
Building and Structures	$69,181		
Services	$55,345		
Misc.	$34,590		
TOTAL DIRECT COSTS		$1,224,503	
Construction and Field Expences	$61,225		
Engineering Expences	$73,470		
Contractors Fees	$67,960		
Contingencies	$135,920		
TOTAL INDIRECT EXPENCES		$338,575	
TOTAL COSTS			$1,563,078

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$10,530	
Replacement Membranes (every 2 years)	$37,170	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (3 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$35,863	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$36,900	
TOTAL OPERATING COSTS		$221,399

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	75	
Number of Systems	4	
Membrane Cost	High	
COST PER SYSTEM		$230,603
TOTAL COST		$922,413

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$922,413		
Shipping Charges	$46,121		
Installation of Equipment	$73,793		
Foundations	$46,121		
Instruments	$55,345		
Piping	$73,793		
Insulation	$92,241		
Electrical	$110,690		
Building and Structures	$92,241		
Services	$73,793		
Misc.	$46,121		
TOTAL DIRECT COSTS		$1,632,671	
Construction and Field Expences	$81,634		
Engineering Expences	$97,960		
Contractors Fees	$90,613		
Contingencies	$181,226		
TOTAL INDIRECT EXPENCES		$451,433	
TOTAL COSTS			$2,084,104

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$14,040	
Replacement Membranes (every 2 years)	$49,560	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (4 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$47,817	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$42,471	
TOTAL OPERATING COSTS		$254,824

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	50	
Number of Systems	6	
Membrane Cost	High	
COST PER SYSTEM		$216,266
TOTAL COST		$1,297,593

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$1,297,593		
Shipping Charges	$64,880		
Installation of Equipment	$103,807		
Foundations	$64,880		
Instruments	$77,856		
Piping	$103,807		
Insulation	$129,759		
Electrical	$155,711		
Building and Structures	$129,759		
Services	$103,807		
Misc.	$64,880		
TOTAL DIRECT COSTS		$2,296,740	
Construction and Field Expences	$114,837		
Engineering Expences	$137,804		
Contractors Fees	$127,469		
Contingencies	$254,938		
TOTAL INDIRECT EXPENCES		$635,049	
TOTAL COSTS			$2,931,788

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$21,060	
Replacement Membranes (every 2 years)	$74,340	
LABOUR		
Supervision of Equipment and Cleaning (1 1/2 shift per day)	$151,406	
ENERGY		
Electrical Power for Pump (6 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$71,725	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$63,706	
TOTAL OPERATING COSTS		$382,237

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	100	
Number of Systems	3	
Membrane Costs	Med.	
COST PER SYSTEM		$144,867
TOTAL COST		$434,602

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$434,602		
Shipping Charges	$21,730		
Installation of Equipment	$34,768		
Foundations	$21,730		
Instruments	$26,076		
Piping	$52,152		
Insulation	$43,460		
Electrical	$52,152		
Building and Structures	$43,460		
Services	$34,768		
Misc.	$21,730		
TOTAL DIRECT COSTS		$786,629	
Construction and Field Expences	$39,331		
Engineering Expences	$47,198		
Contractors Fees	$43,658		
Contingencies	$87,316		
TOTAL INDIRECT EXPENCES		$217,503	
TOTAL COSTS			$1,004,132

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COST OF EQUIPMENT

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$10,530	
Replacement Membranes (every 2 years)	$64,313	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (3 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$35,863	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$42,328	
TOTAL OPERATING COSTS		$253,970

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	75	
Number of Systems	4	
Membrane Costs	Med.	
COST PER SYSTEM		$144,867
TOTAL COST		$579,469

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$579,469		
Shipping Charges	$28,973		
Installation of Equipment	$46,358		
Foundations	$28,973		
Instruments	$34,768		
Piping	$69,536		
Insulation	$57,947		
Electrical	$69,536		
Building and Structures	$57,947		
Services	$46,358		
Misc.	$28,973		
TOTAL DIRECT COSTS		$1,048,839	
Construction and Field Expences	$52,442		
Engineering Expences	$62,930		
Contractors Fees	$58,211		
Contingencies	$116,421		
TOTAL INDIRECT EXPENCES		$290,004	
TOTAL COSTS			$1,338,842

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COST OF EQUIPMENT

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$14,040	
Replacement Membranes (every 2 years)	$85,750	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (4 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$47,817	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$49,709	
TOTAL OPERATING COSTS		$298,252

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	50	
Number of Systems	6	
Membrane Costs	Med.	
COST PER SYSTEM		$135,888
TOTAL COST		$815,328

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$815,328		
Shipping Charges	$40,766		
Installation of Equipment	$65,226		
Foundations	$40,766		
Instruments	$48,920		
Piping	$97,839		
Insulation	$81,533		
Electrical	$97,839		
Building and Structures	$81,533		
Services	$65,226		
Misc.	$40,766		
TOTAL DIRECT COSTS		$1,475,744	
Construction and Field Expences	$73,787		
Engineering Expences	$88,545		
Contractors Fees	$81,904		
Contingencies	$163,808		
TOTAL INDIRECT EXPENCES		$408,043	
TOTAL COSTS			$1,883,787

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COST OF EQUIPMENT

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$21,060	
Replacement Membranes (every 2 years)	$128,625	
LABOUR		
Supervision of Equipment and Cleaning (1 1/2 shift per day)	$151,406	
ENERGY		
Electrical Power for Pump (6 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$71,725	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$74,563	
TOTAL OPERATING COSTS		$447,379

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	100	
Number of Systems	3	
Membrane Costs	Lo.	
COST PER SYSTEM		$117,427
TOTAL COST		$352,282

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$352,282		
Shipping Charges	$17,614		
Installation of Equipment	$28,183		
Foundations	$17,614		
Instruments	$21,137		
Piping	$42,274		
Insulation	$35,228		
Electrical	$42,274		
Building and Structures	$35,228		
Services	$28,183		
Misc.	$17,614		
TOTAL DIRECT COSTS		$637,630	
Construction and Field Expences	$31,881		
Engineering Expences	$38,258		
Contractors Fees	$35,388		
Contingencies	$70,777		
TOTAL INDIRECT EXPENCES		$176,305	
TOTAL COSTS			$813,934

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$10,530	
Replacement Membranes (every 2 years)	$38,588	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (3 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$35,863	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$37,183	
TOTAL OPERATING COSTS		$223,100

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	75	
Number of Systems	4	
Membrane Costs	Lo.	
COST PER SYSTEM		$117,427
TOTAL COST		$469,709

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$469,709		
Shipping Charges	$23,485		
Installation of Equipment	$37,577		
Foundations	$23,485		
Instruments	$28,183		
Piping	$56,365		
Insulation	$46,971		
Electrical	$56,365		
Building and Structures	$46,971		
Services	$37,577		
Misc.	$23,485		
TOTAL DIRECT COSTS		$850,173	
Construction and Field Expences	$42,509		
Engineering Expences	$51,010		
Contractors Fees	$47,185		
Contingencies	$94,369		
TOTAL INDIRECT EXPENCES		$235,073	
TOTAL COSTS			$1,085,246

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$14,040	
Replacement Membranes (every 2 years)	$51,450	
LABOUR		
Supervision of Equipment and Cleaning (1 shift per day)	$100,937	
ENERGY		
Electrical Power for Pump (4 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$47,817	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$42,849	
TOTAL OPERATING COSTS		$257,092

TUBULAR MEMBRANE SYSTEM COST

Flux Rate (gfd)	50	
Number of Systems	6	
Membrane Costs	Lo.	
COST PER SYSTEM		$110,163
TOTAL COST		$660,978

MEMBRANE BASED OIL REMOVAL PROCESS
TOTAL COST OF INSTALLED EQUIPMENT

Purchase Cost of Equipment	$660,978		
Shipping Charges	$33,049		
Installation of Equipment	$52,878		
Foundations	$33,049		
Instruments	$39,659		
Piping	$79,317		
Insulation	$66,098		
Electrical	$79,317		
Building and Structures	$66,098		
Services	$52,878		
Misc.	$33,049		
TOTAL DIRECT COSTS		$1,196,370	
Construction and Field Expences	$59,819		
Engineering Expences	$71,782		
Contractors Fees	$66,399		
Contingencies	$132,797		
TOTAL INDIRECT EXPENCES		$330,796	
TOTAL COSTS			$1,527,167

MEMBRANE BASED OIL REMOVAL PROCESS
OPERATING COSTS

MATERIALS		
Membrane Cleaning Chemicals ($13.50/lb, 10 lb per 500 gal. soln., 26 cleans per yr.)	$21,060	
Replacement Membranes (every 2 years)	$77,175	
LABOUR		
Supervision of Equipment and Cleaning (1 1/2 shift per day)	$151,406	
ENERGY		
Electrical Power for Pump (6 X 50 HP X 0.7457 X 24 X 365 X 3.66 cents/KW)	$71,725	
CONTINGENCIES & MAINTENANCE		
Other Operating Expences (20 % of other expences)	$64,273	
TOTAL OPERATING COSTS		$385,639

APPENDIX M

OPERATING STRATEGIES FOR OILY WATER EMULSION CONCENTRATION BY UF

APPENDIX M

OPERATING STRATEGIES FOR OILY WATER EMULSION CONCENTRATION BY UF

The major operational factors which affect the productivity (flux) of a tubular membrane array, are transmembrane pressure, flow rate through the tube, operating temperature and the operating cycle employed.

The significance and interelation of these factors may be explained with the aid of Figure 1. At sufficient flow rates flux is linearly dependent on pressure. This condition corresponds with line A in Figure 1. At low flow, there is a critical transmembrane pressure above which flux is independent of pressure. This corresponds with the conditions of Curve C in Figure 1. Under these conditions flux is controlled by the gel-layer deposited on the membrane. Flux may be increased by further increases in flow (which reduces the thickness of the gel-layer) as illustrated by Curve B of Figure 1.

The operating cycle chosen can have a major effect on membrane productivity, and system capital and operating cost. The effect on membrane productivity is illustrated with the aid of Figure 2, in which the y-axis represents flux throughout the duration of a batch concentration cycle and the x-axis represents elapsed time from the start or wastewater concentration factor.

In batch concentration instantaneous flux values start at F_o and decline progressively with time to F_f. The average flux rate

FIGURE 1
Effect of Pressure and Flow on Flux

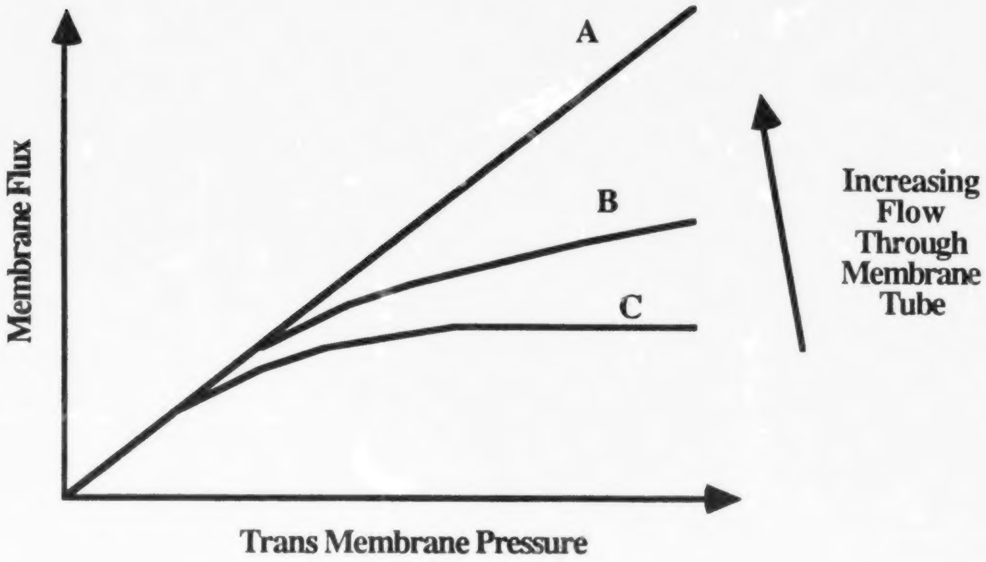
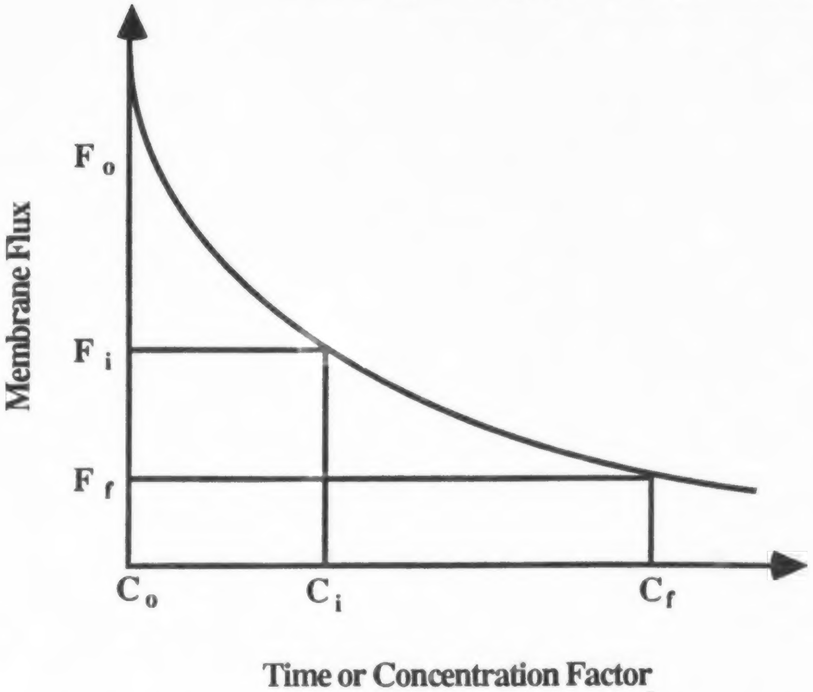


FIGURE 2
Effect of Operating Cycle on System Flux



(F_{av}) can be found by graphical integration of the area under a flux vs time curve.

By contrast in a continuous feed and bleed system the wastewater concentration factor and membrane flux will reach equilibrium values of C_f and F_f respectively. It is apparent that F_f is lower than the value of F_{av} for the corresponding batch concentration.

The advantages of continuous operation may be achieved at higher flux rates than with continuous feed and bleed operation by using staged continuous operation. As an example consider a two stage continuous operation with repumping between stages, with the first stage operating at concentration C_i and flux F_i, while the second stage operates at C_f, F_f. It is apparent that the average flux is higher than a single stage feed and bleed system operating at C_f, F_f. While the average flux of the membrane array increases with an increasing number of stages, so does system complexity, and more than three stages are generally uneconomical.

In practice most operational oily water UF systems use a batch concentration cycle. The reasons are economy, simplicity and a forgiving design. The latter may be understood better by considering that the precise value of the final concentration factor is not usually critical to operation or process costs, and that changes in influent characteristics do not cause process failure but only change the final level of concentration achieved.

ENHANCEMENT TECHNIQUES

There are several techniques commonly used to enhance operation of industrial UF systems used for treating oily water emulsions.

In order to minimize the separation of free oil during processing, pH is often adjusted upwards from 6.5 - 7.0 to 8.5 - 9.0, using sodium hydroxide. This has the effect of shifting the ionization equilibrium of some types of surface active components present in emulsions (fatty acids, anionic synthetic detergents), towards the freely ionized forms, which then disassociate. The resulting negative charge on the surfactant species helps stabilize the emulsion. Addition of anionic detergent can further stabilize the emulsion.

Raising the pH also helps inhibit bacterial growth. Bacterial growth is undesirable in that it adversely affects operating performance and can cause objectionable odours. The addition of an organic biocide can also be used to limit bacterial growth.

The addition of alkali surfactant and biocide can often be achieved conveniently by dispensing a manufacturer's "emulsion make-up package" which contains two or more of these components. Such packages are commonly available from the specialty chemical suppliers who provide the stamping or cutting oils or cleaners to the manufacturing or washing operation from which the wastewater originates.

Increased temperatures result in higher membrane productivity due to reduced viscosity. The relationship is typically linear, and is usually significant enough to be considered as a design variable. Glues and other materials used in the membrane module usually limit the operating temperature to 40-60°C but this can be extended by using improved system components. With typical emulsions the energy of pumps alone can raise the temperature into the range of 40°C to 50°C. A temperature coefficient of 1.0 gfd per degree C is normal in most systems.

Above 65°C increases in temperature may be counterproductive. Most synthetic industrial emulsion in use today contain appreciable quantities of non-ionic surfactants, which have cloud points of 70°C and higher. On reaching its cloud point, the surfactant will lose its ability to function and its ability to stabilize the emulsion. Emulsions in which non-ionic surfactant is predominent may destabilize totally in 1 hour or less at temperatures above 65-70°C.

DESTABILIZATION TECHNIQUES

Since flux generally declines with increasing concentration, an oil level may eventually be achieved at which it is more economical to destabilize the emulsion rather than to concentrate it further.

The methods commonly used for destabilization are acid addition and thermal destabilization. The use of these methods after a 90% or greater volume reduction involves much lower quantities of chemicals or heat input than would be required on the whole wastestream.

FLUX RESTORATION

The use of flux restoration techniques to bring performance of membranes back to original values at the start of each batch or during feed and bleed operation are an integral part of membrane system operation.

In recent years, with the steady improvement and matching of membrane formulations to the emulsion type, and the development of pH tolerant, cellulosic and chemically resistant membranes, flux restoration has become much easier. Greater chemical resistance and pH tolerance means that a wider variety of cleaning agents may be used without damaging the membrane, while the noncellulosic membranes are all but immune to microbiological attack. The improved formulations have enhanced the fouling resistence of the membranes and helped lengthen the intervals between cleaning and the extent of cleaning required. The frequency of chemical cleaning is typically once every two weeks or longer.

Flux restoration can be accomplished by introduction of a low oil content feedstream such as the introduction of a new batch to the process tank during batch concentration. Efficiency can be enhanced by operating the membrane array briefly at lower pressure and higher volocity, which can actually shave away the accumulated gel layer.

A variety of cleaning agents including alkaline detergent cleaning solutions are most commonly used. These may be supplemented with a low pH cleaner to remove precipitated inorganic material which may be chemically bound to the membrane.

Strategies practiced in other UF applications but which are not generally applicable in oily water treatment include sponge-ball cleaning, the use of enzyme detergents.